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WEST INDIAN BULLETIN.

The Journal of the Imperial Department of Agriculture for the West Indies.

VOLUME XVIII.

ISSUED UNDER THE AUTHORITY
OF THE

COMMISSIONER OF AGRICULTURE

FOR THE WEST INDIES.

Barbados: Advocate Co., Ltd., Bridgetown.

London: Messrs. Dulau & Co., Ltd., 34-36, Margaret Street, Cavendish Square, W.I.

West India Committee, 15, Seething Lane, E.C.

1921.

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WEST INDIAN BULLETIN

VOLUME XVIII.

REPORT OF THE TROPICAL AGRICULTURAL COLLEGE COMMITTEE.

For a great many years the opinion has been freely expressed that an Agricultural College is needed in the West Indies, so that orderly and definitely formulated instruction may be given in matters pertaining to West Indian tropical agriculture, which is the basis of practically all the commerce and enterprise of these colonies. Following upon these early West Indian expressions of ideas, there has been a wide-spread desire for Agricultural Colleges in other British tropical possessions, and some eight or ten years ago this question was freely discussed, and opinions recorded that it was desirable that there should be such colleges both in the Eastern and Western Tropics. The matter remained in abeyance until a little more than a year ago, when a movement in favour of establishing a college in the West Indies took active shape, and resolutions were passed in Trinidad, Antigua, and Jamaica, directing the attention of the Secretary of State for the Colonies to the question, and asking that he would take steps to make possible the establishment of the desired college in one of the West Indian colonies.

As the outcome of this, Lord Milner, the present Secretary of State for the Colonies, in August last appointed a Committee to consider the desirability of establishing a Tropical Agricultural College in the British West Indies, and to advise generally on the subject.

The Committee presented their Report on November 25. This Report the Secretary of State has now forwarded for the consideration of the Governments of all the West Indian colonies, expressing general approval of the proposals which it contains, and requesting that the widest publicity may be given to it. The Report is reproduced below.

To THE RIGHT HONOURABLE VISCOUNT MILNER, G.C.B., G.C.M.G., Secretary of State for the Colonies.

My Lord,

The Committee appointed by your Lordship on August 25, 1919, to consider the desirability of establishing a Tropical Agricultural College in the British West Indies, and matters connected therewith, beg leave to submit their Report as follows :—

2. The Committee comprises the following members :—

DR. A. E. SHIPLEY, LL.D., Sc.D., F.R.S., *Chairman*, Master of Christ's College, Cambridge, and Deputy Vice Chancellor.

LIEUT-COLONEL SIR DAVID PRAIN, C.M.G., C.I.E., F.R.S., *Deputy-Chairman*, Director of the Royal Botanic Gardens, Kew.

SIR NORMAN LAMONT, Bart., Member of the Legislative Council of Trinidad and Tobago.

THE HON. GIDEON MURRAY, M.P., late Administrator of St. Lucia.

SIR OWEN PHILIPPS, G.C.M.G., M.P.

SIR HENRY FRANK HEATH, K.C.B., Secretary to the Department of Scientific and Industrial Research.

SIR FRANCIS WATTS, K.C.M.G., D.Sc., Imperial Commissioner of Agriculture for the West Indies.

SIR EDWARD DAVSON, President of the Associated Chambers of Commerce of the West Indies.

DR. C. A. BARBER, C.I.E., Sc.D., F.L.S., Sugar-Cane Expert for India.

MR. ROBERT RUTHERFORD, Chairman of the West India Committee.

MR. HENRY ALEXANDER TROTTER, Deputy-Chairman of the West India Committee.

MR. ELIOT ARTHUR DE PASS, Chairman of the Jamaica Standing Committee of the West India Committee.

DR. J. B. FARMER, M.A., D.Sc., F.R.S., Professor of Botany, Imperial College of Science and Technology.

CAPTAIN A. W. HILL, M.A. Sc.D., F.L.S., Assistant Director of the Royal Botanic Gardens, Kew.

MR. W. H. HIMBURY, General Manager of the British Cotton Growing Association.

MR. J. W. McCONNEL, Member of the Empire Cotton Growing Committee, Board of Trade.

Mr. G. Moody Stuart, West Indian Estates' Proprietor.

Mr. Algernon E. Aspinall, C.M.G., B.A., *Hon. Secretary*, Secretary of the West India Committee.

Sir Henry Frank Heath, K.C.B., was unable to attend any of the meetings, and was represented by Mr. A. Abbott. Dr. C. A. Barber, C.I.E., Sc.D., F.L.S., was co-opted a member of the Committee.

3. At the first meeting of the Committee, held on September 16, Dr. A. E. Shipley, LL.D., Sc.D., F.R.S., and Lieut.-Colonel Sir David Prain, C.M.G., C.I.E., F.R.S., were appointed Chairman and Deputy-Chairman, respectively, and Mr. Algernon E. Aspinall, C.M.G., B.A., Honorary Secretary.

4. The terms of reference to the Committee are set out in your Lordship's letter of August 25, 1919, to the members of the Committee as follows :—

To consider whether it is advisable to found an Agricultural College in the West Indies, and, if in the Committee's opinion the answer to this question is in the affirmative, to make recommendations in regard to the situation, constitution, management, scope, finance, staff, buildings, and any other matters which in the opinion of the Committee require to be considered in connexion with the foundation of the proposed College.

5. *Desirability of Establishing a College.*—The Committee desire to state at the outset that they are unanimously of the opinion that steps should be taken at an early date to found a Tropical Agricultural College in the British West Indies.

6. The need for such an institution has for some years been increasingly apparent. In order that our Colonies and Possessions may be placed in a position to compete successfully with foreign countries in the production and marketing of the staples of the tropics, it is of paramount importance that their young men should be afforded opportunities for instruction in the principles of agriculture, and in the cultivation and preparation for market of tropical produce of every kind, including especially, sugar, and its by-products rum and molasses, cacao, coffee, cotton, coco-nuts, rice, citrus and other fruits—notably bananas, and dye-woods, many of which commodities constitute the raw materials employed in the manufactures of the Mother Country.

7. Equally important is the need which exists of making full provision for the prosecution of research, and for the training of scientific investigators in matters pertaining to tropical agriculture amid suitable surroundings, and for creating a body of British expert agriculturists well versed in the knowledge of the cultivation of land in the tropics, and of scientific advisers possessing an intimate knowledge of the means of combating pests and diseases the control of which is fundamentally essential to the successful development of agriculture in the tropics.

8. It has been brought before the notice of the Committee that Agricultural Colleges have been established successfully in

Porto Rico and Hawaii, besides a University in Louisiana, which possesses, moreover, an unrivalled Sugar School at Audubon Park, New Orleans, and they would regard it as a reproach if Great Britain were to remain behind the United States in this matter. The Committee desire especially to emphasize the fact that the establishment of a Tropical Agricultural College in the West Indies is a matter of Imperial concern. Such a college would be of no less importance to the Mother Country than to colonies immediately concerned, having regard to the present necessity of developing production throughout the Empire to the utmost extent, and to the opportunities which it would afford to students trained in agriculture at Universities in the United Kingdom to continue their training as post-graduates in the tropics.

9. *Situation of the College.*—Sir Leslie Probyn, K.C.M.G., Governor of Jamaica; Major Sir John Chancellor, K.C.M.G., D.S.O., Governor of Trinidad and Tobago; Mr. T. A. V. Best, C.M.G., C.B.E., Colonial Secretary of Trinidad and Tobago, and Mr. P. C. Cork, C.M.G., late Colonial Secretary of Jamaica, attended before the Committee and submitted evidence regarding the claims of their respective colonies to selection as the head-quarters of the proposed College. The Committee also had the advantage of perusing a valuable memorandum submitted by Sir Sidney Olivier, K.C.M.G., C.B., late Governor of Jamaica, who, as Secretary of the Royal Commission of 1897, visited all the West Indian islands and British Guiana, and thus has an intimate knowledge of their conditions and requirements.

10. After carefully considering the matter in all its aspects, and with special reference to the geographical position and grouping of the various West Indian islands and British Guiana, and to the general desire that the College should be closely associated with the Imperial Department of Agriculture, the Committee recommend that the Tropical Agricultural College be established in Trinidad, provided that the Government of Trinidad and Tobago is prepared to afford it adquate support and every reasonable facility.

11. In arriving at this decision the Committee were influenced by the fact that Trinidad possesses a wide variety of industries and is easy of access by steamer communication to residents in the neighbouring islands and British Guiana.

12. The Committee recognize that the claims of Jamaica have great weight, this colony having a population approximating to that of the rest of the West Indian islands, and a still wider variety of industries than that possessed by Trinidad. They feel, however, that difficulties of intercolonial transit would form a serious obstacle to the transfer of the Imperial Department of Agriculture to Jamaica if, as is so much to be desired, the islands of the Lesser Antilles are still to derive immediate advantage from the work of that useful body.

13. Mr. E. A. de Pass strongly urged the claims of Jamaica; but the Committee reluctantly feel that, owing to its geographical position, Jamaica must to some extent be treated as a separate unit in this matter. In view, however, of the great importance

of that island's agricultural interests, there should, in their opinion, be intimate co-operation between the Jamaica Agricultural Department and the Imperial Department of Agriculture and the Committee believe that it would be of advantage to Jamaica to identify itself with the proposed Tropical Agricultural College. The Committee further suggest that the usefulness of the organization at present existing in Jamaica for agricultural training and research might be extended by a modification in the case of that island of the financial proposals contained in a later paragraph of this Report, so that Jamaica's contribution and the porportion of any Imperial grant added thereto, might be divided between the funds of the proposed College and a local Agricultural School.

The claims of Barbados were also closely considered, but could not be entertained owing to the smaller range of that island's products.

14. *Incorporation.*—It being obviously desirable, that the Tropical Agricultural College should, from its inception, be established as a legal entity, the Committee have had under codsideration the various means by which this could be effected.

15. They are strongly of opinion that it would add materially to the standing and influence of the College if it were to be incorporated by Royal Charter. They are advised, however, that it will be better to defer petitioning the King for the grant of a Royal Charter until the College has been successfully established with every prospect of permanency.

16. Whilst, therefore, advocating that it should be the ultimate object of the Governing Body of the Tropical Agricultural College to petition His Majesty for the grant of a Royal Charter of Incorporation, the Committee recommend that, at the outset, the College be incorporated in the United Kingdom as a Company limited by guarantee, and that application be made to the Board of Trade for a licence, under Section 20 of the Companies (Consolidation) Act of 1908, whereby the word 'Limited' may be omitted from its name.

17. They append to this Report documents marked A and B showing what procedure should be adopted in this connexion. In recommending the Incorporation of the College in the United Kingdom, the Committee have not lost sight of the question of possible liability to Income Tax, etc. They are advised, however, that in view of the fact that the objects of the College would be a charitable purpose within the meaning of those words as used in the Income Tax Acts, it would be entitled to exemption from taxation in respect of income derived from any investments representing an endowment fund, and that monies received for expenditure on general purposes would be similarly exempt from Income Tax.

18. *Constitution.*—With regard to the Constitution of the proposed College, the Committee desire to make the following recommendations :—

(1) They regard it as highly desirable that an intimate

relationship shouldbe established between the Imperial Department of Agriculture and the Tropical Agricultural College.

After careful consideration, the Committee recommend that in the first instance the Imperial Commissioner of Agriculture be the Principal of the College, and that, when occasion arises for a new appointment, the Trustees and Governors (to be constituted as hereinafter provided for) nominate a Principal and, in consultation with the Secretary of State for the Colonies, arrange that such Principal also holds the position of Imperial Commissioner of Agriculture, should the Secretary of State desire to appoint him to that office.

(2) The Trustees and Governors of the College should be a body composed of (*a*) ex-officio, (*b*) nominated, and (*c*) co-opted members, and should constitute a Governing Body whose meetings should ordinarily be held in London.

The Governing Body should administer the affairs of the Tropical Agricultural College, should hold and expend all monies belonging to the College, and should appoint and/or dismiss all officers of the College. They should appoint from their own body a Finance Committee whose meetings should ordinarily be held in London, and should also appoint from their own body an Executive Committee whose meetings should be held in the colony in which the Agricultural College is situated.

The ex-officio members of the Governing body should be two in number, namely :—

(*a*) The senior Financial Officer for the time being of the colony in which the College is situated.

(*b*) The Principal of the Tropical Agricultural College.

The nominated members of the Governing Body might vary in number, and should include :—

(*a*) Two members appointed by the Secretary of State for the Colonies, of whom one might ordinarily be able to serve as a member of the Finance Committee, and the other as a member of the Executive Committee (to be constituted as hereinafter provided for).

(*b*) One member appointed by the Academic Board of the Tropical Agricultural College, who should ordinarily serve also on the Executive Committee.

(*c*) A group of members nominated by the contributing Colonies The number of such Trustees and Governors might vary, but the Committee anticipate that the number might be six, viz., one each nominated from Barbados, British Guiana, Jamaica, Trinidad and Tobago, the Leeward Islands, and the Windward Islands.

(*d*) A group of members nominated by contributing industries. In this case, again, the number of such Trustees and Governors might vary, but the Committee consider it possible that the number might be five, viz., one each representing the cacao, cotton, coco-nut, fruit-growing, and sugar industries, respectively.

(c) Three members nominated by and representing Academic Institutions in the United Kingdom. The Committee regard such representation as a matter of the highest consequence, and suggest that, for purposes of nomination, those institutions deemed suitable by the Governing Body be placed on a roster and invited to nominate representatives in such order as they may determine. The Committee further recommend that the three Academic Institutions first invited to nominate each one Trustee and Governor be the University of Cambridge, the University of Glasgow, and the Imperial College of Science and Technology of London.

The co opted members of the Governing Body should be fout in number, of whom two should ordinarily be invited in respec- of their ability to serve also as members of the Finance Committee, and the other two in respect of their ability to serve also as members of the Executive Committee.

The Finance Committee should be composed of such Trustees and Governors as the Governing Body determine, and the duties of the Finance Committee should be defined from time to time by the Governing Body.

The Executive Committee should include the two ex-officio Trustees and Governors of the College, and such other Trustees and Governors as the Governing Body determine, provided always that any member of the Governing Body should be at liberty to attend any meeting of the Executive Committee, and in the event of his being present, should be entitled to vote. The duties of the Executive Committee should be defined from time to time by the Governing Body.

The two ex-officio Trustees and Governors should remain members both of the Governing Body and of the Executive Committee so long as they continue to hold the offices in virtue of which they respectively serve.

The four co-opted Trustees and Governors should continue in Office for a period of four years only; but it should nevertheless be competent for the Governing Body to reappoint a co opted member at the expiration of his period of service.

The several nominated Trustees and Governors should continue in office for a period of four years only, subject to the proviso that the odd numbers of those first nominated as Trustees and Governors should be appointed to serve for six years Except in the case of Academic Institutions in the United Kingdom invited by the Governing Body to nominate representatives, it should be competent for each nominating authority to reappoint a nominated member at the expiration of his period of service. In the case of Academic Institutions, permission to this effect might be granted by the Governing Body.

The normal composition of the Governing Body as suggested may be summarized as follows :—

A. Ex-officio members (also ex officio members of the Executive Committee) 2

Nominated members :—

Representing the Secretary of State for the Colonies	2
Representing the Academic Board of the Tropical Agricultural College	1
Representing the Contributing Colonies, possibly	6
Representing the Contributing Industries, possibly	5
Representing Academic Institutions in the United Kingdom	3
C. Co-opted members	4
Total	23

(3) The Academic Board should be composed of the Principal and the Professors of the Tropical Agricultural College and should have charge of the Students of the College, and be responsible to the Governing Body for the discipline of the Students and for the details of the instruction imparted to them.

(4) The Staff of the College should consist of the Principal, and of such Professors (ex-officio members of the Academic Board), and Lecturers (who should not be members of the Academic Board), together with other assistants, as the Governing Body may from time to time appoint to serve. The Staff should, from the inception of the College, include teachers with the status of Professors in the following subjects :—

1 General Agriculture ;
2 Mycology ;
3 Entomology ;
4 Agricultural Chemistry ;
5 Organic Chemistry ;
6 Agricultural Bacteriology ;
7 Agricultural and Physiological Botany ;
8 Genetics ;
9 Sugar Technology ; and

10. Agricultural Engineering and Physics :
and teachers with the status of Lecturers in the two subjects :—

11. Stock and Veterinary Science ; and

12. Book-keeping.

19. In connexion with the Staff, the Committee beg to recommend strongly that one of the duties delegated at the outset by the Governing Body to their Finance Committee be that of devising a suitable scheme of pensions for the members of the College Staff ; and that one of the duties delegated to their Executive Committee be that of arranging that provision be made for the granting to members of the Staff of periods of Study leave in addition to any furlough to which, as teachers in the College, they may be entitled.

20. *Curriculum.*—Though they have recommended (*See* § 18 (3) above) that the details regarding the instruction to be given to Students of the Tropical Agricultural College should be settled

by the Academic Board which it is proposed to set up, the Committee submit the following suggestions as to a curriculum, put forward by Sir Francis Watts, K.C.M.G., D.Sc., with the general principles of which they are in agreement :—

'(*a*) A junior course of instruction in tropical agriculture extending over two, or possibly three, years. This course should be arranged to meet the requirements of youths leaving the Secondary Schools of the colonies who intend to follow ordinary agricultural pursuits probably in the colonies from which they come. There should be some educational standard of requirement for admission to the course. This might be an examination of the College or certain recognized examinations might be accepted in substitution, such, for example, as the Senior Local Examination of Oxford or Cambridge, or other similar examinations. This course of instruction should embrace general agricultural science and agronomy, together with such practical instruction in the elements of field agriculture as the equipment of the College permits.

'(*b*) A senior course of similar instruction extending over not less than four years

'(*c*) A course of two years' instruction in more advanced tropical agriculture for students who have undergone a course of instruction in general agriculture in a recognized institution, such as a University, a University College, or an Agricultural College. This course would practically coincide with the final two years' teaching of the last named course (*b*).

'(*d*) Post-graduate study of special agricultural subjects in their tropical application, as for example, Entomology, Mycology, Chemistry, Plant Breeding, and the general study of special crops such as sugar, cacao, cotton, coco-nuts, rice, and a variety of others, to be arranged to meet the requirements of individual students. These studies would be carried on through the College in association with the Imperial Department of Agriculture, and, by arrangement with the respective Governments, through the medium of such Local Agricultural Departments and Experiment Stations as appear to be particularly suited for the work. It is probable that facilities in connexion with these studies may be offered by the owners of sugar and other factories, and by the owners of plantations, and that courses of instruction to meet the needs of individual students may be arranged by the Academic Board to meet special cases'

21. *Sugar School.*—Recognizing the urgent need which exists for the provision of scientific and technical training in sugar manufacture, the Committee strongly recommend that a Sugar School equipped with a complete plant on a small, but working, scale be established in connexion with the Tropical Agricultural College. They believe that the leading sugar

machinery manufacturing firms would be willing to contribute different portions of this plant.

22. *Oil Technology.*—In view of the growing importance of the oil industry of Trinidad, it has been suggested to the Committee that, in the event of it being decided to establish the Tropical Agricultural College in Trinidad, a technical branch might be added to that institution, where men could obtain practical training in oil technology and the control of oil-fields. Students would have exceptional opportunities of acquiring knowledge, inasmuch as they would be able to visit the oilfields periodically, while the presence in the island of many fully qualified engineers, geologists, drillers, etc., would permit of lectures being given from time to time on all subjects associated with petroleum.

23. *Financial Arrangements.*—In approaching the question of ways and means, the Committee have had constantly in view the fact that, though the Tropical Agricultural College would be located in the West Indies, it would be, to a great extent, Imperial in its scope and activities, it being expected, for example, that the senior students would be post-graduates of British Universities and Colleges, and that many of the students trained in the College would be available for service throughout the Empire. Apart from this, they would point out that, as stated in an earlier paragraph of their report (§ 8), it would be manifestly to the benefit of the Mother Country that production should be extended in the British West Indies on scientific and remunerative lines. They would emphasize, moreover, in this connexion, that, of the American Agricultural Colleges to which reference has already been made, that of Porto Rico, at any rate, is subsidised by the United States Government. In order to provide the requisite ways and means for the establishment and maintenance of the West Indian Tropical Agricultural College, the Committee recommend that:—

(1) For the establishment of the College a Fund of £50,000 and upwards should be raised by private subscription.

(2) For the maintenance of the College—

(*a*) Annual contributions should be invited from the various West Indian Colonies on the basis of the equivalent of, say, ½ per cent. of their average revenue during the preceding three years, and each Colony, in return for its contribution, should have the right to nominate a representative to sit on the Governing Body of the College and to enjoy special privileges in respect of its students; it being understood in this connexion that the constituent islands of the Windward Islands' group should be regarded as one Colony.

(*b*) Annual contributions should be invited from the Imperial Government, as grants-in aid, on the basis of £1 for every £1 contributed by the Colonies, the liability of the Imperial Government, however, not to exceed £15,000 in one year.

(*c*) Voluntary contributions should be invited from industrial organizations and individuals interested in tropical industries.

The Committee feel very strongly that the claim for Imperial assistance would be fully justified by reason of the Imperial nature of the work to be undertaken.

They also feel that, if their recommendations meet with your Lordship's approval, it would greatly facilitate the collection of contributions from those interested in tropical industries if your Lordship would yourself issue the appeal.

24. *College Buildings.*—The Committee consider that the question of College Buildings is one which should be remitted to the Governing Body when duly constituted. They would, however, express the hope that the Government of whichever West Indian colony may be selected as the site of the Tropical College, will meet the Trustees and Governing Body in a liberal spirit in this connexion, and they desire to record that they have already received a generous offer of accommodation on a substantial scale from the Governor of Jamaica. It need hardly be added that the Committee attach the greatest importance to the buildings being erected in healthy surroundings, and on thoroughly hygienic lines.

25. *Imperial Department of Agriculture.*—Having regard to their recommendation that the Tropical Agricultural College should be closely associated with the Imperial Department of Agriculture the Committee consider it as within the terms of reference to emphasize, as they desire most earnestly to do, the importance of establishing that Department on a more permanent basis after the expiration of the present Imperial grant.

26. The Committee wish in conclusion to express their obligation to Mr. Algernon E. Aspinall, C.M.G., B.A., for his services as their Honorary Secretary, and for the great assistance which he has given them in their work.

We have the honour to be, My Lord,

Your Lordship's obedient servants,

A. E. SHIPLEY (*Chairman*).
D. PRAIN.
NORMAN LAMONT.
ERMINE MURRAY (for Gideon Murray)
OWEN PHILIPPS.
FRANCIS WATTS.
EDWARD DAVSON.
A. ABBOTT (for Sir H. Frank Heath).
C. A. BARBER.
R. RUTHERFORD.
H. A. TROTTER.
E. A. DE PASS.
J. BRETLAND FARMER.
ARTHUR W. HILL.
W. H. BIMBURY.
JOHN W. McCONNEL.
GEO. MOODY STUART.

ALGERNON E. ASPINALL,
Hon. Secretary,
22nd October, 1919.

After this report had been approved, the Committee held a further meeting to consider the following cablegram received on November 5, by Mr. E. A. de Pass, from Mr. A. W. Farquharson, Chairman of the Jamaica Imperial Association:—

> 'Financial majority Elected Members agree support initial grant £50,000 and £5,000 annually towards the Agricultural College if Jamaica made hea 'quarters Imperial Department of Agriculture.—FARQUHARSON.'

The Committee, whilst adhering to the recommendations contained in their report, suggested that, in the event of Trinidad and the Windward and Leeward Islands not seeing their way to support adequately the proposed Tropical Agricultural College—a contingency which the Committee hope may not arise—the possibility of establishing the College in Jamaica may again be considered. The question as to the site of the Imperial Department of Agriculture does not come within the terms of reference to the Committee, although they have found it necessary in the course of their report to refer to this important aspect of the question.

ALGERNON E. ASPINALL,
Hon. Secretary.

25th November, 1919.

Attached to the Report are two appendices, A and B, referred to in section 17, pointing out the procedure to be adopted in cases of application to the Board of Trade for a licence, and suggesting rules and articles for forming an Association.

STUDIES OF INHERITANCE IN COTTON.

1. THE INHERITANCE OF COROLLA COLOUR.

BY S. C. HARLAND, D.Sc., (Lond.),
Assistant for Cotton Research on the Staff of the Imperial Department of Agriculture for the West Indies.

INTRODUCTION.

So-called 'wild cottons' occur in every island of the West Indies. They are found chiefly near villages, as scattered single plants in gardens. The leaves and roots are used to some extent for medicinal purposes. The origin of these cottons is unknown, but presumably they are survivals from the time when short staple cotton was grown on a large scale in the West Indies. Native types are still grown on a commercial scale, under the name 'Marie Galante', in the Grenadines, a group of small islands lying between St. Vincent and Grenada.

A large number of native cottons have been grown in pedigree culture, and it has been found that all breed true, even to the most minute morphological characters Broadly speaking, the natives fall into two groups: (a) glabrous, with 5-lobed leaves and pitted bolls; (b) hirsute, with predominantly 3-lobed leaves and smooth bolls. None of the types examined agree in their characters with the published descriptions of any known species. It is perhaps sufficient to say that group (a) is allied to the braziliense-peruvianum series, while group (b) is near to the purpurescens-vitifolium series. All types in the first group are susceptible to leaf-blister mite (*Eriophyes gossypii*, Banks). Many, but not all, of the second group, are immune.

How can the existence of this group of Elementary Species of Gossypium be accounted for? It may be suggested that many different kinds of cotton were tried during the period when short staple cotton was grown in the West Indies. According to Watt (1907), Rohr made a tour in 1790 of all the neighbouring islands and mainland of South America, in order to study cotton cultivation, and to collect seeds for trial in St. Croix. Natural crossing between different types would be more or less common, and when cotton cultivation was abandoned, only a few more or less scattered plants would be left, kept alive by labourers in their gardens for medicinal and other domestic purposes. Under these conditions there would be no opportunity for natural crossing, and since the old plants would be replaced by self-sown seedlings every four or five years, it may easily be imagined that in course of time such isolated plants would become completely homozygous and when taken into pedigree culture would behave as elementary species. Doubtless many of the so-called species which have been described from the West Indies have originated in this way. It would easily be possible to collect a hundred or more different pure breeding West Indian natives.

It may be noted that *Ricinus communis*, L., provides an example of another group of Elementary Species in the West Indies, which has doubtless originated in the same way.

The experiments which are here recorded, deal with the inheritance of corolla colour in crosses between some Native cottons and Upland and Sea Island.

Methods.

All seed used in these experiments was from self-fertilized flowers. It would not have been possible to use seed from unprotected flowers, for natural crossing is of frequent occurrence in the West Indies. The flowers were selfed by tying the end of the unopened flower bud with string. This eliminates the greatest source of natural crossing, but there remains the possibility of an occasional natural cross effected by thrips or staphylinid beetles, both of which occur abundantly in cotton flowers.

Corolla Colour.

Previous Investigations.

The inheritance of corolla colour in cotton has been studied by Balls (1912), Leake, (1911), and McLendon (1912).

Balls worked with inter-Egyptian crosses, and also with crosses between Egyptian and Upland. In the cross between the two Egyptian varieties, Afifi (golden) by Sultani (lemon), the F_1 was intermediate. Great difficulty was found in classifying the F_2, some flowers being matched first to one and then to the other of the three colour types. He concluded that probably two pairs of allelomorphs were involved in the cross.

In regard to crosses of Egyptian and Upland, he says:—

'The crosses of Egyptian with Upland have behaved in a similar manner. The cross of yellow—whether lemon or golden—with white or cream, has always given an intermediate F_1. In F_2, we have obtained ratios which approached very closely to 1:2:1, but with a constant excess of the paler parental colour type. Testing this on the assumption of a 9:3:4 ratio, we obtained consistent results up to a certain point. Whites and some full yellows bred true, some intermediates threw out all colours like the F_1; other intermediates threw whites only, while yet others threw only the full parental yellow, giving approximately 3:1 ratios in both cases. It seemed at one stage that the double-pair hypothesis had met all contingencies until the following test was applied.

'A family raised from an F_3 plant which bore the intermediate colour had given twenty-two intermediates to seven full yellows. Six of these F_4 intermediates were grown into F_5: the obvious expectation was that four should breed true to the intermediate colour. The actual result was that none threw any yellows at all, but all threw whites. These whites were not, moreover, of the same colour as the parent white, but much nearer the intermediate itself. . . .

'From this evidence it is plain that petal colour in crosses of Egyptian by Upland may be controlled by not less than three pairs of allelomorphs.'

McLendon investigated the inheritance of corolla colour in crosses of upland and Sea Island. He says:—

'Yellow petals and yellow anthers crossed with white petals and buff anthers give an F_1 generation in which the colour in each pair of characters is intermediate in intensity. In the F_2 generation the expected 3:1 ratio does not obtain, but the parental forms reappear in varying proportions in the different crosses, with continuous variation between the extremes; . . . . . the ratios for these two pairs of characters are the same in all instances in the F_2 generation'.

Leake worked with Indian cottons. He established that full yellow and white constitute an allelomorphic pair, full yellow being dominant. Full yellow and pale yellow also form an allelomorphic pair, full yellow again being dominant. The relation between pale yellow and white was not investigated.

Indian cottons do not hybridize with New World cottons, and it is thus not surprising that the mode of inheritance in inter-Indian crosses should be found to be fundamentally different.

The Experimental Results.

The corolla colour of the types under investigation ranges from a deep golden yellow to a pale cream, and there are at least six different shades of colour which breed true. It will therefore be convenient to set forth in tabular form a classification of the types worked with.

CLASSIFICATION OF TYPES OF COROLLA COLOUR.

Variety.	Corolla colour.	Class.
Upland	White (pale cream)	0
Native 1	Cream	1
Native 2	Pale yellow	2
Native 3	Medium yellow	3
Sea Island ...	Deep yellow	4
Native 4	Very deep yellow	5

Ten different crosses were made, viz. 0×2, 0×3, 0×4, 0×5, 2×3, 2×4, 2×5, 3×4, 3×5, and 4×5. Of these, F_2 results are available for crosses 0×2, 0×3, and 0×5. In the cross 0×3, a number of F_3 cultures were grown.

Before passing on to the detailed discussion of the results obtained in the various crosses, it may be said that a cross between any two of the above shades gave an intermediate F_1. In all F_2 families, the parental and F_1 colour types appeared, but there may have been other intermediate colour forms in addition. If the difference between the parent colours is slight, it will be understood that exact classification of the F_2 is impossible. Balls (1912) in discussing inheritance of corolla colour in Egyptian-Upland hybrids, states that ordinary matching methods are not sufficiently precise, and that some form of colorimetric grading is needed. With this view the writer agrees, but since in these experiments colorimetric grading was not practicable, all that could be done was to use Upland (class) 0 as an 'analyser', and divide the second and third generation plants into white and various shades of yellow. In the cross 0×5, the deepest class (5) was also distinguished in F_2.

THE CROSS 0 × 2 (WHITE × PALE YELLOW).

The F_1.

Intermediate.

The F_2.

Segregation took place into the parental and F_1 forms, but no shade deeper than class 2 appeared. Classifying the plants into yellow and white, the following numbers were obtained :—

Yellow.	White.
82	30

The numbers obtained approximate to the ordinary 3:1 ratio, but in the absence of F_3 results it is inadvisable to put forward further comment.

THE CROSS 0 × 5 (WHITE × VERY DEEP YELLOW).

The F_1.

Intermediate.

The F_2.

A series of forms was obtained ranging from 0 to 5. The results were :—

Very deep yellow.	Intermediate.	White.
1	72	4

Here it may be suggested that at least two factors are involved in this cross, for the ratio of yellow to white is 18:1. In the absence of more detailed evidence, the results of this cross will not be further discussed.

THE CROSS 0 × 3 (WHITE × MEDIUM YELLOW).

The F_1.

Intermediate.

The F_2.

The results are presented below :—

COROLLA COLOUR. F_2 RESULTS OF THE CROSS 0 × 3 (WHITE × MEDIUM YELLOW).

Family.	Yellow.	White.
1	35	6
2	90	20
3	57	15
Total	182	41
Ratio	4·4 :	1·0

The F_3.

The F_3 results of the cross 0 × 3, will be found in the table below.

COROLLA COLOUR. F_3 FAMILIES OF CROSS 0 × 3
(WHITE × MEDIUM YELLOW).

Family.	F_2 Parent.	No. of Plants.	Yellow (1-3)	White (0)	
1	Yellow	35	35	0	
2	,,	20	20	0	
3	,,	19	19	0	
4	,,	6	6	0	
5	,,	11	11	0	
6	,,	4	4	0	
7	,,	24	24	0	
8	,,	5	5	0	
9	,,	38	27	11	
10	,,	39	21	18	
11	,,	38	28	10	Y:W : : 477:180
12	,,	39	31	8	Ratio 2·7:10
13	,,	37	30	7	
14	,,	20	16	4	
15	,,	37	29	8	
16	,,	24	12	12	
17	,,	17	14	3	
18	,,	30	24	6	
19	,,	30	25	5	
20	,,	31	27	4	
21	,,	8	7	1	
22	,,	22	20	2	
23	,,	21	16	5	
24	,,	28	20	8	
25	,,	9	6	3	
26	,,	24	17	7	
27	,,	31	27	4	
28	,,	10	7	3	
29	,,	26	22	6	
30	,,	29	16	13	
31	,,	22	12	10	
32	,,	9	6	3	
33	,,	13	7	6	
34	,,	12	12	8	
35	,,	27	20	7	
86	White	53	2	51	
37	,,	31	0	31	
38	,,	19	2	17	
39	,,	19	0	19	
40	,,	20	1	19	
41	,,	36	0	36	
42	,,	16	0	16	
43	,,	19	1	18	
44	,,	19	1	18	
44	,,	14	0	14	
45	,,	31	4	27	

A survey of the results of the cross 0 × 3 (white × medium yellow) leads to the following main conclusions :—

1. The ratio of yellow to white in F_2 is 4·4:1·0. If it is assumed that yellow and white constitute an allelomorphic pair, the deficiency in the number of whites needs explanation. The deficiency is shared by all three F_2 families.
2. Eight families from F_2 yellows threw yellows only in F_3. Three families are, however, so small that they cannot with certainty be said to be homozygous. Twenty-seven families from F_2 yellows threw yellow and white in proportions not far from the 3:1 ratio. The departures from the 3:1 ratio in individual families, however, are more than would be expected through mere fluctuation, and it may be that the close approximation to the 3:1 ratio is due to combining families with an excess of whites, with other families containing a deficiency.
3. The eleven familes from F_2 whites, which are expected to breed true in F_3, threw an occasional yellow in six families. The proportions in which the yellows occur are not suggestive of any ordinary Mendelian ratio, and the present writer is inclined to believe that thrips or staphyllinid beetles have caused natural crossing.
4. It is not without hesitation that the hypothesis that medium yellow and white constitute an allelomorphic pair is put forward With the evidence available, however, no other satisfactory explanation of the results can be given.

The Correlation between Corolla and another Colour.

In his crosses of Upland and Sea Island, McLendon (1912) found complete correlation between petal and anther colour. The cross 0 × 5, is one of very deep yellow petal and deep yellow anther by white petal and buff anther. In respect to anther colour, the F_1 was intermediate. In F_2 were obtained :—

Yellow petal Yellow anther.	White petal Yellow anther.	Yellow petal Buff anther.	White petal Buff anther.
72	2	1	0

There is thus little evidence of correlation between petal and anther colour in this cross. It is worthy of note that the parental combination of white petal and buff anther does not appear.

Summary.

1. The West Indian native cottons appear to constitute a group of Elementary Species, the origin of which may be ascribed to distant natural crossing between more or less widely separated types.

The segregates from these crosses have passed through many generations with no opportunity for further crossing, and have thus gradually become homozygous.

2. Crosses have been studied between Upland and Sea Island, and various types of native.

3. Six different shades of corolla colour, ranging from white to very deep yellow, were used in these experiments.

The F_1 of a cross between any two colour types was intermediate.

5. The F_2 results of the cross pale yellow by white, indicate that these two colours are possibly allelomorphic.

6. The F_2 results of the cross very deep yellow by white, indicate that two pairs of factors are involved.

7. In the cross medium yellow by white, in which a considerable number of F_3 families were grown, the evidence shows that probably medium yellow and white constitute an allelomorphic pair of characters.

8. In one cross the relation of petal colour to anther colour was studied. No evidence of correlation between these characters was found.

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MANURIAL EXPERIMENTS WITH SEA ISLAND COTTON IN ST. VINCENT IN 1918-19, WITH SOME NOTES ON THE CONTROL OF CERTAIN DISEASES BY SPRAYING.

BY S. C HARLAND, D.Sc. (Lond.),

Assistant for Cotton Research on the Staff of the Imperial Department of Agriculture for the West Indies.

INTRODUCTION.

In two former papers (1917, 1918,) the present writer has given an account of the manurial experiments which have been conducted at the St. Vincent Experiment Station during the period 1912-18. These experiments were continued in 1918-19, and the present paper contains an account of the results obtained in that season.

METHODS OF STUDY.

In most respects the methods of cultivation and treatment of the plots were similar to those of the previous season.* One half of each plot, however, was sprayed with Burgundy mixture, in order to see whether the two most destructive diseases of cotton in St. Vincent, Angular Spot and Soft Rot, could be controlled. As all the plots were treated similarly, i. e. half being sprayed and the other half unsprayed, it is evident that definite conclusions respecting the effect of different manures on yield can still be arrived at.

OBJECTS OF INVESTIGATION IN 1918-19.

The main objects of the investigation during the season 1918-19 were as follows :—

1. To see whether the general conclusions previously arrived at respecting the effects of different manurial combinations on yield would be confirmed by further study.
2. To investigate the effects of different manurial combinations on the percentage of bolls to flowers.
3. To observe the differences induced in yield, and in the form of the flowering and bolling curves by the environmental conditions of 1918-19, and by treatment with fungicide.

THE RESULTS OF THE MANURIAL EXPERIMENTS FROM 1912-18.

The general results of the manurial experiments for the past seven years are presented in Table I. From these results the comparative value of the different manures applied can be estimated, for when increases in yield result from the application of particular manures, it is important to determine to what extent treatment is responsible.

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* It is to be noted that the same combinations of manure are applied to the same plots each year. The plots are permanently devoted to the manurial experiments.

The conclusions which may be drawn from an analysis of Table I by statistical methods are as follows:

1. The probable error for a single plot for each of the seven seasons 1912-18, may be tabulated thus :—

Season.	Probable error.
1912-13	13·7
1913-14	20·6
1914-15	6·9
1915-16	10·8
1916-17	15·2
1917-18	15·2
1918-19	10·4

To eliminate the effects of treatment, the average of each group of plots is taken as 100. and each plot is expressed as a percentage of this. Thus, the average of the combined percentages is also 100. As pointed out by Bishop, Grantham, and Knapp (1917), this method introduces an inaccuracy in all cases where the average of each group of plots would not have approximated to the average of all the plots had they all been similarly treated.

2. The probable error for a single plot for the combined results of 1912-18 is 5·3 per cent. The fact that the probable error for the seven-year period is less than that of any single year shows that some variations are compensated for as the period increases in length.

3. From Table I it is seen that all the manured plots have given an increase over the unmanured during the seven-year period. How much of this increase is significant? To be conservative, the probable error for a single plot may be increased from 5·3 to 5·5 per cent. For each manurial combination there are three plots the results of which can be averaged. The probable error of the mean of three plots is 5·5 divided by $\sqrt{3}$ or 3·1 per cent. A difference of 3·1 × 1·41 or 4·4 per cent. would be necessary to give even chances. That is, if during the seven years one manurial combination outyields another by 4·4 per cent., the chances are even that the difference is the result of treatment. To ensure practical certainty that the difference is due to treatment, it is necessary to accept odds of 30 to 1. With these odds, a difference is not conclusive unless it amounts to 4·5 times the probable error or 14 per cent. if a difference may be obtained in either direction, or 3·8 times the probable error or 12 per cent. if the difference is expected in one direction only. With this information, it is now possible to discuss the significance of the differences in yield obtained during the seven-year period.

Nitrogen.

Nitrogen, applied at the rate of 30 lb. per acre as sulphate of ammonia, has given an increased yield over no-manure of 18 per cent. As an increased yield of 12 per cent. is significant, it may be concluded that a yield of at least 6 per cent. greater is due to treatment.

Phosphate.

Phosphate, applied at the rate of 40 lb. per acre as basic slag, has given precisely the same increase as nitrogen (18 per cent The same conclusions apply to the use of this manure as to nitrogen.

Potash.

Potash, applied at the rate of 30 lb. per acre as sulphate of potash has produced an increased yield over no-manure of 42 per cent. An increase of 30 per cent. may be accepted as due to treatment. Potash also gives 20 per cent. greater yield than nitrogen or phosphate, and of this 8 per cent. is significant. Thus, of the three elements, potassium is much the most important for St. Vincent soils, and its use will undoubtedly be attended by profitable results, provided that the price of potash manures is not too high. The conclusion that potassium is the element most necessary for cotton under the soil conditions of St. Vincent is also strikingly confirmed by the results obtained during the season 1918-19, when the potash plots yielded 62 per cent. more seed cotton than the unmanured plots. Of this 62 per cent. increase, 39 per cent. is due to treatment.

The physiological affection known in the United States as 'rust,' and in St Vincent as the 'red leaf disease', is the result of potash deficiency. The chief symptom of this disease is a premature reddening or browning of the leaves, which fall at an early age. Most of the cotton lands of St. Vincent are now showing signs of potash deficiency to an alarming degree, and the results of these manurial experiments are valuable as showing how vital to the industry is the supply of available potash in the soil.

In 1918-19, as in the previous season, 'rust' appeared in every plot of the manurial series, though the plots which received potash were less severely attacked. All the manurial plots are now below a reasonable standard of fertility, for even in the complete manure plots the plants are small and lacking in vigour. This indicates that where cotton is grown on the same land for several years in succession, fertility cannot be maintained without using greater quantities of manure than those used in these experiments.

Phosphate and potash.

The combination of phosphate (40 lb. per acre) and potash (30 lb. per acre) produces an increase over no-manure of 28 per cent., of which 14 per cent. may be regarded as significant. It has been pointed out previously (Harland, l. c.) that the combination of phosphate and potash has, in recent years, yielded less than potash alone, though no explanation of the phenomenon could be put forward. It will be of interest to summarize the results of the past seven years :—

Season.	Yield with potash, lb. per acre.	Yield with potash and phosphate, lb. per acre.	Per cent. increase with potash alone.
1912-13	753	812	-11
1913-14	605	501	+21
1914-15	777	699	+11
1915-16	728	764	- 5
1916-17	404	344	+17
1917-18	1,040	819	+27
1918-19	803	625	+28
Mean 1912-18	730	656	+11

In every year except 1912 and 1915, the addition of phosphate to potash lowered the yield and the mean of the potash plots during the seven-year period is 11 per cent. above that of the phosphate and potash. This result is 3·6 times the probable error, and it may be regarded as certain that, in some way not yet understood, the addition of basic phosphate tends to reduce the effect of a potash manure.

Nitrogen, phosphate and potash.

The plots which received a complete artificial manure consisting of nitrogen (30 lb as sulphate of ammonia), phosphate (40 lb. as basic slag), and potash (30 lb. as sulphate of potash), have yielded 30 per cent. more than the no-manure plots. Of this, 18 per cent. may be regarded as due to treatment. The yield with this combination, however, is 9 per cent. less than with potash alone. It is therefore possible that the lowering effect of phosphate on yield comes into play also with this combination, and that if this constituent had been omitted, the yield would have been greater.

Cotton-seed meal.

The plots which received cotton-seed meal at the rate of 600 lb. per acre have yielded 15 per cent. more than the no-manure plots. Of this, no more than 3 per cent. may be regarded with certainty as due to treatment. Obviously, cotton-seed meal, applied at this rate, is of very little value as a manure for cotton. In round figures, 600 lb. of cotton-seed meal contain 7 lb. potash, 25 lb. nitrogen, and 1 lb. phosphoric acid. Since it has been shown that potash is the chief manurial constituent required by St. Vincent soils, it is evident that cotton-seed meal should be applied in far greater quantity if favourable results are to be looked for. It may be remarked at this stage that, although cotton-seed meal is used fairly generally as a manure in St. Vincent, it is seldom or never applied in such large amount as in these manurial experiments. The plots which have received potash alone have yielded 23 per cent. more than the cotton-seed meal plots, and of this increase, 11 per cent. is certainly due to treatment.

Cotton-seed meal, phosphate and potash.

The plots receiving a complete manure consisting of nitrogen (as cotton-seed meal 600 lb. per acre), phosphate (40 lb. per acre), and potash (30 lb. per acre), have yielded 42 per cent. more than the no-manure plots. This result is practically the same as that secured with potash alone, and it seems certain that when sufficient potash is present other constituents have very little effect on yield. We do not know of course, to what extent the yield has been lowered through the use of phosphate, and it will be important in the near future to determine the manurial value of fertilizers in which this constituent is omitted.

The Results of the Manurial Experiments in 1918-19.

In Table II will be found the results of the number of flowers and bolls produced by each of the manurial plots, together with the percentage of bolls to flowers, the yield of each plot in pounds of seed cotton per acre and the increase or decrease of each combination of manure over the unmanured plots. It has been point-

ed out previously, that the probable error for a single plot for 1918-19 is 10·4 per cent. The probable error for the mean of three plots is thus 10·4 divided by 3 or 6 per cent A difference in yield between two manurial combinations cannot therefore be regarded as significant, unless it amounts to 3·8 times the probable error, i. e. unless the difference amounts to 23 per cent. With this information, the results of the experiments of 1918-19 would appear to indicate :—

1. Nitrogen is better than no manure by 9 per cent.
2. Phosphate is better than no manure by 6 per cent.
3. Potash is better than no manure by 39 per cent.
4. Phosphate and potash is better than no-manure by 3 per cent., but inferior to potash alone by 5 per cent.
5. Nitrogen, phosphate and potash is better than no manure by 33 per cent. It is possible, but not certain, that this combination is inferior to potash alone, on account of the lowering effect of phosphate on yield.
6. Cotton-seed meal is better than no manure by 3 per cent., but is inferior to potash alone by 5 per cent.
7. Cotton-seed meal, phosphate and potash, is better than no manure by 54 per cent.

These results corroborate in large part the conclusions already established by a study of the combined results from 1912-18.

The Relation between the Percentage of Bolls to Flowers and Manurial Treatment.

From the results of 1916-17 it was concluded that the percentage of bolls to flowers was not influenced to any extent by manurial treatment. In 1917-18 the question was again studied, and it was noted that a strong positive correlation existed between the yield of a plot in pounds per acre, and the percentage of bolls to flowers. It was therefore argued that factors which are favourable to high yield are also favourable to a high percentage of bolls to flowers.

On reconsidering the results of 1916-17, it becomes evident that although variation in the percentage of bolls to flowers is not great, the correlation between percentage of bolls to flowers and yield is high and positive ($r = 0{\cdot}69 \pm 0{\cdot}08$).

The correlation for the season 1918-19 is low and positive, being $r = 0{\cdot}189 \pm 0{\cdot}08$. It is thus not statistically significant. It may be concluded that, while in general a positive correlation exists between yield and percentage of bolls to flowers, the correlation is apt to be obscured by the various environmental conditions to which the plants are exposed during their period of growth.

The Flowering and Bolling Curves of 1918-19, Compared with Those of the Two Previous Seasons.

In previous discussions of the manurial experiments, diagrams have [illegible] showing the flowering and bolling curves [illegible] combinations. In this paper the curves of the separate manurial combinations will not be given, as they differ from each other merely in amplitude, and have the

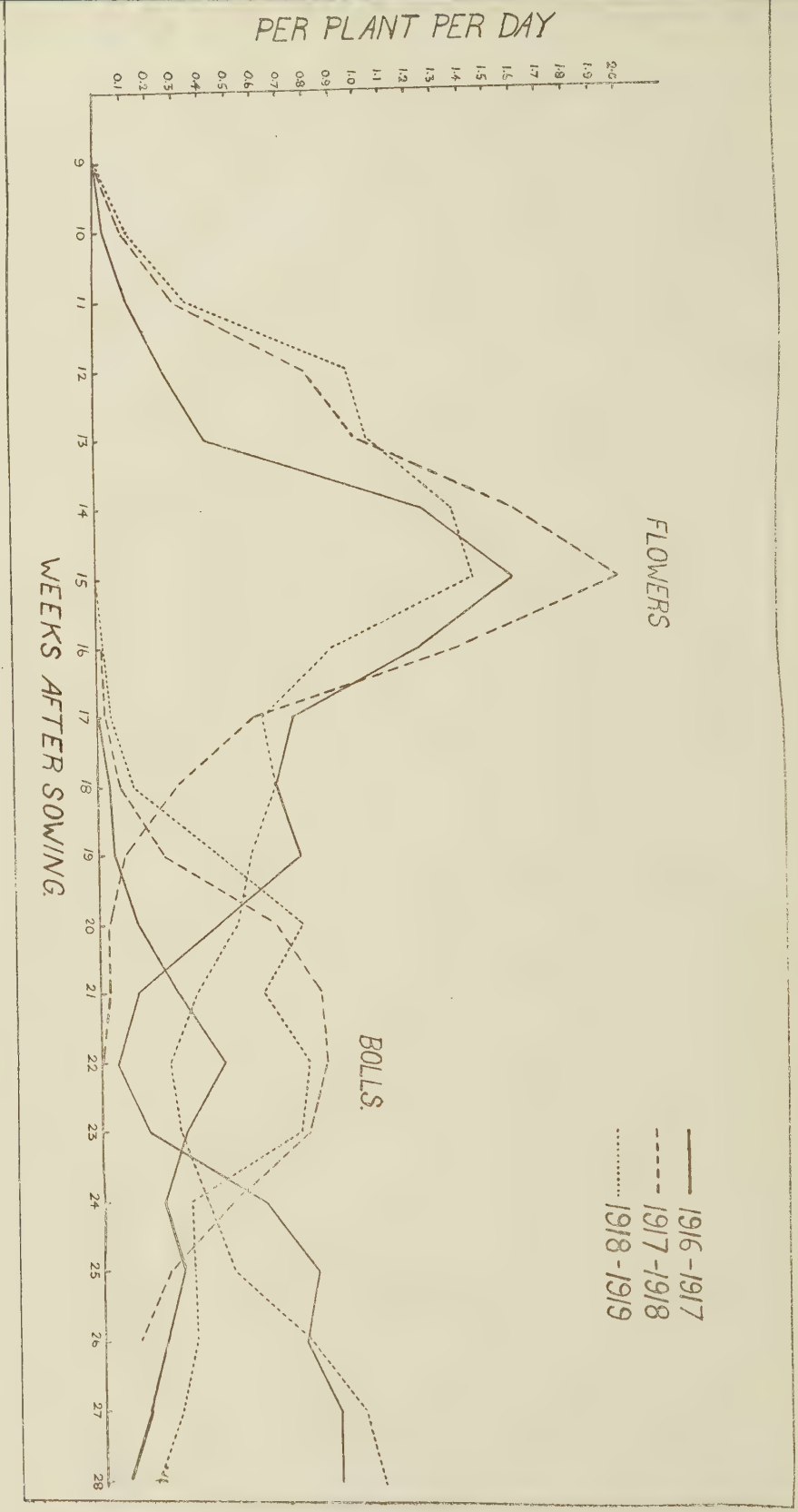

PLATE 1.

Comparison of flowering and bolling curves of 1918-19 with those of the two previous seasons.

same general form. Variation in the form of the flowering and bolling curves which is the result of season is of interest, and accordingly in Plate I will be found the flowering and bolling curves of the combined twenty-four plots for the three seasons 1916-17, 1917-18, and 1918-19.

A study of these curves leads to the following main conclusions :—

1. In all three seasons flowering commenced on the 57th day from sowing, and the number of flowers became large enough to indicate on the graphs in the 10th week after sowing.
2. The maximum rate of flowering is reached in the 15th week from sowing.
3. The minimum rate of flowering is reached in the 22nd week from sowing.
4. The flowering curve rises to a second maximum in 1916-17, and 1918-19, but the second flowering period is earlier in the former season.
5. The bolling curves in all three seasons follow more or less closely the course of their corresponding flowering curves.
6. In both 1916-17, and 1918-19, no flowers from the second part of the flowering curve produced bolls. In the former season all bolls were infected with internal boll disease by cotton stainers, while in the latter the flowers were produced too late in the season to mature bolls. According to the present law of St. Vincent, all cotton plants must be destroyed by the end of March, and it follows that if the second set of flowers is to be of any value, it must be produced before the end of January.

The Conditions under which the Plants Were Grown in 1918-19.

In a previous paper (Harland 1917) a comparison was made between the growing conditions of 1916-17, and 1917-18. It was pointed out that in the former season heavy rains fell during the most critical part of the growing season, causing severe attacks of External Boll disease, and the Soft Rot disease due to *Phytophthora* sp. In addition, there was a large amount of shedding of both buds and bolls. The percentage of bolls to flowers in 1916-17 was only 17·2.

In 1917-18 conditions were favourable throughout the season. There was no excessive rainfall, and thus the loss from fungoid disease was small. Cotton stainers were few in number and did no appreciable damage. Owing to this desirable combination absence of stainers and of excessive rainfall the crop was good, and the percentage of bolls to flowers rose to 48·2.

In 1918-19 the weather conditions were less favourable than in the previous season; 36 inches of rain fell during September, October, and November, as against 25 in the corresponding months of 1917. The stainer position was favourable, no appreciable numbers being noted until the bulk of the crop was

picked. The percentage of bolls to flowers was 37, implying a loss of 63 per cent. of the flowers produced.

It is necessary to emphasize the fact that in normal seasons there may be a loss of 50-60 per cent. of the flowers produced by the plants in field crop. Much of the loss in St. Vincent is through disease, for the number of bolls naturally shed is small. Ewing (1918) has published figures showing the loss experienced under the conditions of Mississippi. (U.S.A). He estimates that in Upland varieties, 60 per cent. of the bolls may be shed, but he states that certain varieties are more subject to shedding than others. The present writer had already made observations on this point in the Sea Island pedigree selections at the St. Vincent Experiment Station. Certain Sea Island strains, practically immune to shedding, have been isolated.

The Spraying Experiments in 1918-19.

The External Boll disease, due to *Bacterium malvacearum*, Sm., has been mentioned as being responsible for much loss of crop during periods of heavy rainfall. At these times the Soft Rot disease, due to *Phytophthora* sp., also causes great destruction of bolls. It was with the object of determining whether these diseases could be controlled, that the experiments described below were carried out.

Rolfs (1915) reported that in South Carolina the Angular Spot disease (External Boll disease) could be controlled by six sprayings with fungicide.

In the season 1917-18, preliminary spraying experiments with Burgundy mixture were made. The formula used in making up the spray was the well-known one recommended by Dr. A. S. Horne. The composition was as follows :—

Copper sulphate	9·75 oz.
Washing soda	11·00 oz.
Milk	0·75 pint
Water	3·00 gals.

In using this spray it was soon apparent that at the above strength too much injury was caused to the plants. In the 1918-19 experiments the spray was used first at half strength, but it was still too strong. The mixture was then further diluted to 40 per cent. strength.

The details of the spraying experiments may be set forth thus :—

Date of spraying.		Strength of spray.
August	19	50 per cent.
"	28	"
September	2	40 per cent.
"	10	"
"	19	"
"	26	"
October	9	"
"	23	"
November	5	"
"	19	"
December	6	"
"	20	"

Altogether thirteen sprayings were given to the plants. The 40-per cent. spray appeared to injure the plants somewhat, but it was impossible to dilute the mixture further without destroying its efficacy as a fungicide. The injury was done chiefly to the buds, many of which shrivelled and turned black.

Effect of Spraying on the Angular Spot Disease.

Every plant in the manurial series was examined between October 29 and November 1, in order to determine the amount of infestation with Angular Spot. The plants were then about thirteen weeks old. The results of this examination are presented below.

(a) *Sprayed Plots*

Frequency array showing percentage of plants affected with Angular Spot in twenty-four sprayed plots.

	Percentage of plants affected.												
	0	1	2	3	4	5	6	7	8	9	10	11	Mean.
No. of plots ...	3	–	3	1	4	1	4	–	1	3	2	1	5·0

(b) *Unsprayed Plots.*

Frequency array showing percentage of plants affected with Angular Spot in twenty-four unsprayed plots.

	Percentage of plants affected.									
	20	30	40	50	60	70	80	90	100	Mean.
No. of plots ...	1	–	1	2	4	4	5	5	2	72·1

The mean percentage of plants affected in the sprayed plots was 5, while that in the unsprayed was 72. Thus the Angular Spot disease, so far as the leaves are concerned, can be controlled almost completely by the use of Burgundy mixture. It may be mentioned that no cases of Soft Rot were seen in the sprayed plots, while a fair number were noted in the unsprayed sections.

Effect of Spraying on Yield.

In Table III are presented the following data from both sprayed and unsprayed plots: (a) number of flowers per plant, (b) number of bolls per plant, (c) percentage of bolls to flowers. It will be quite convenient to summarize the main points of this table thus:—

	Sprayed.		Unsprayed.		Difference ÷ Probable error.
Mean flowers per plant ...	31·0	1·05	49·0	1·64	
Difference			+18·0	1·95	9·2
Mean bolls per plant ...	12·0	0·43	18·0	0·62	
Difference			+ 6·0	0·76	7·9
Percentage bolls	39·8	0·76	37·0	0·86	
Difference	+ 2·8	1·15			2·3

From this summary it will be seen that the number of flowers and bolls per plant is greater in the unsprayed than in the sprayed plots. Since the difference between sprayed and unsprayed is eight or nine times the probable error, it cannot be due to chance.

The percentage of bolls to flowers is greater in the sprayed than in the unsprayed plots. The superiority of the sprayed plots is not, however, statistically significant, since the difference is only twice the probable error.

Effect of Spraying on the Rates of Flowering and Bolling.

The rates of flowering and bolling of the sprayed and unsprayed plots are shown in Plate 2. The main features of importance are as follows :—

1. The flowering curve of the unsprayed plots reaches a maximum during the week ending November 21, (15th week). The flowering curve of the sprayed plots reaches its maximum at the same time, but begins some three weeks later. Delay in the commencement of flowering is due to loss of buds through spraying. This loss also causes the greater amplitude of the curve from the unsprayed plots.

2. After the week ending December 12 (17th week) the flowering curve of the sprayed plots maintains itself at a considerably higher level than that of the unsprayed plots. An examination of the plants revealed the reason for this. The 40-per cent. spray did not injure the buds to any extent. Growth of the main axis of unsprayed plants ceased when from twenty-five to thirty fruiting branches were formed. The main axis of sprayed plants was still elongating at a time when that of unsprayed plants had ceased. Many sprayed plants produced over forty fruiting branches.

It is clear that loss of buds and of young bolls will have the effect of lengthening the vegetative period. A plant which is prevented from producing its normal quota of flowers or bolls by shedding, will endeavour to make up for the loss by throwing out fruiting branches higher up the stem, and these will produce flowers at a later period Some observations of Ewing (l.c.) may be referred to. He conducted an experiment in which all flowers were removed from the plants on the day they opened. On plants from which flowers were removed a large number of flowers were being produced daily, when flowering of control plants had practically ceased. It is necessary to emphasize the important fact that the normal form of the flowering curve may be greatly modified by shedding of either buds or bolls.

It will be recalled that the flowering curve of the 1916-17 plots does not descend so abruptly after reaching its maximum as does that of the following season. Furthermore, while the average plant of 1916-17 produced upwards of forty fruiting branches that of 1917-18 had less than thirty.

3. The shedding in 1916-17 was very great, while that of 1917-18 was comparatively small. It seems probable that the production of a second mode in the flowering curve in 1916-17 was partially due to stimulation of vegetative growth following extensive shedding of the first set of buds and bolls.

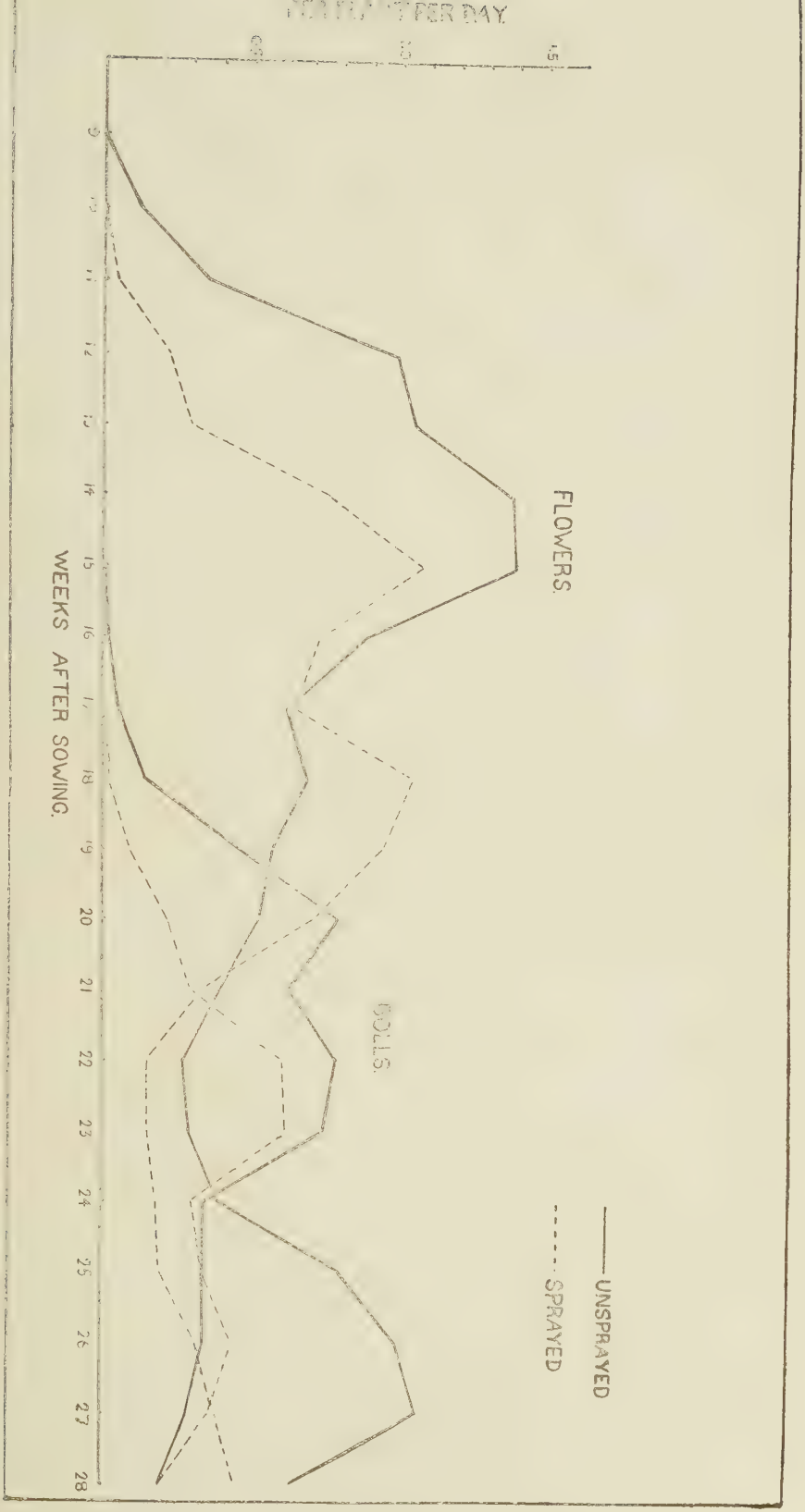

PLATE 2.

Flowering and bolling curves of the sprayed and unsprayed plots.

4. The rates of bolling of Plate 2 do not require any particular comment. The form of the corresponding flowering curve is followed more or less clearly.

General Considerations on the Spraying Experiments

The results of these experiments on the control of fungoid diseases of cotton by spraying with Burgundy mixture indicate that the disease due to *B. malvacearum*, Sm., which is known variously as Angular Spot, Black Arm, and External Boll disease, can be controlled in so far as the Angular Spot aspect is concerned. The Angular Spot disease on the leaves can be controlled, but this is of little importance unless infection of the bolls can be prevented. There is a difference of 3 per cent. in the percentage of bolls to flowers in favour of the sprayed plots. This is not statistically significant, and it must therefore be concluded that spraying is quite useless to control External Boll disease. In regard to the control of the Soft Rot disease, the question must be left open. It is possible that the loss from this disease could be lessened by spraying during periods of heavy rain. An epidemic of Soft Rot is capable of destroying half the crop in a few days.

Summary.

The significance of the manurial experiments with Sea Island cotton, which have now been carried on for seven years, is discussed in detail. It remains to summarize the main features of the experiments, and to emphasize those points which may be made use of in agricultural practice.

1. After being grown on the same land for a number of years, a practice which is general in St. Vincent, the cotton crop responds markedly to applications of both artificial and organic manures.

2. The size of the crop, leaving insect pests and fungoid diseases out of account, is limited by the supply of potash in the soil, although signs are not wanting that lack of nitrogen is already becoming seriously felt.

3. The characteristic sign of potash exhaustion, the 'rust' disease, now appears on most of the cultivated lands of the colony. It is now attracting much attention, and is known locally as the 'red leaf' disease, a term which well describes its chief symptom. The warning given by the present writer in the second paper of this series has apparently not been given serious consideration by growers, but it may now be restated. Most of the cotton lands of St. Vincent are depleted of potash and organic matter to an alarming degree, and will soon cease to give remunerative crops. The cotton crop of St. Vincent is not now limited by the incidence of insect pests or fungoid diseases, but by the supply of available plant food in the soil. It is plainly necessary to import artificial potash fertilizers.

4. The use of phosphate as a manure is not to be recommended since the combination of potash and phosphate is inferior to potash alone.

5. Cotton-seed meal alone cannot be used in an economical manner as a manure for cotton. It should be supplemented by applications of potash and pen manure. If cotton is grown as a rotation crop with cane, a sound agricultural practice, it would be better to utilize the cotton-seed meal and pen manure for the cane crop, and apply an artificial fertilizer containing potash to the succeeding cotton crop.

6. The time of maturing of the cotton crop is not affected by manurial treatment.

7. Differences in manurial treatment cause no notable differences in the percentage of bolls to flowers.

8. Under the tropical conditions of St. Vincent, there is great uniformity in the time at which flowering and bolling begin, reach their maximum, and finish. The bulk of the first crop is picked from the 21st to the 24th weeks from sowing.

9. With the increasing amount of control which has been obtained over the cotton stainer, the chief sources of loss of crop are now (a) shedding of buds and b lls, (b) External Boll disease, and Soft Rot disease. External Boll disease greatly increases the loss from shedding. The experiments concerning shedding are not yet concluded, but in regard to the control of the two above-mentioned diseases, it may be said that while spraying is useless for the control of External Boll disease, further experiments are needed to determine its effects on the Soft Rot disease.

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Table I.

GENERAL RESULTS OF THE MANURIAL EXPERIMENTS FROM 1912-18.

Yields Stated in Pounds of Seed-cotton per acre.

Manure.	Plot.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	Mean.	Per cent. gain over no manure.
No manure.	1 a	943	789	529	392	220	459	521	514	–
	1 b	476	578	735	463	242	528	592		
	1 c	569	352	606	724	248	459	375		
Nitrogen	2 a	989	719	543	452	128	276	543	607	+18
	2 b	6[illegible]8	471	750	756	301	627	902		
	2 c	978	596	740	953	344	750	520		
Phosphate.	3 a	901	545	676	389	115	332	564	607	+18
	3 b	939	438	750	708	358	769	733		
	3 c	855	391	733	777	349	800	618		
Potash.	4 a	733	852	878	581	345	896	822	730	+42
	4 b	779	547	761	720	375	1,064	863		
	4 c	746	417	691	883	492	1,161	725		
Phosphate and potash.	5 a	759	647	689	776	307	712	522	856	+28
	5 b	938	555	695	595	369	972	701		
	5 c	830	302	713	922	356	772	652		
Nitrogen, phosphate and potash.	6 a	811	594	599	839	316	606	705	669	+30
	6 b	719	479	705	859	540	1,098	838		
	6 c	356	382	698	803	438	892	772		
Cotton-seed meal.	7 a	784	759	724	578	228	530	483	593	+15
	7 b	873	383	699	672	361	729	608		
	7 c	505	199	640	609	407	903	787		
Cotton-seed meal, phosphate and potash.	8 a	831	712	9[illegible]8	665	485	1,128	1,003	733	+42
	8 b	876	539	756	737	418	875	798		
	8 c	553	349	661	581	630	1,016	837		

TABLE II.

GENERAL RESULTS OF THE MANURIAL EXPERIMENTS IN 1918-19.

Manure.	Plot.	Flowers.	Bolls.	Per cent. bolls.	Mean.	Yield lb. per acre.	Mean.	Per cent. gain on no manure.
No manure.	1 a	5,454	2,371	43·5	37·8	521	496	–
	1 b	7,634	2,691	35·3		592		
	1 c	4,948	1,706	34·5		375		
Nitrogen.	2 a	5,672	2,471	43·6	38·2	543	655	+32·0
	2 b	9,239	4,105	44·4		902		
	2 c	8,928	2,365	26·5		520		
Phosphate.	3 a	6,694	2,564	38·3	37·3	564	638	+28·6
	3 b	8,211	3,336	40·6		733		
	3 c	8,509	2,810	33·0		618		
Potash.	4 a	8,970	3,741	41·7	37·1	822	803	+61·9
	4 b	9,777	3,926	40·2		863		
	4 c	11,218	3,297	29·4		725		
Phosphate and potash.	5 a	5,848	2,375	40·6	34·2	522	625	+26·0
	5 b	9,408	3,188	33·9		701		
	5 c	10,539	2,964	28·1		652		
Nitrogen, phosphate and potash.	6 a	8,419	3,206	38·1	37·1	705	772	+55·6
	6 b	10,511	3,813	36·3		838		
	6 c	9,515	3,510	36·9		772		
Cotton-seed meal.	7 a	5,505	2,198	39·9	42·6	483	626	+26·2
	7 b	6,148	2,766	45·0		608		
	7 c	8,341	3,580	42·9		787		
Cotton-seed meal, phosphate and potash.	8 a	10,507	4,562	43·4	40·7	1,003	879	+77·2
	8 b	8,896	3,633	40·8		798		
	8 c	10,033	3,809	38·0		837		

Table III.

SHOWING NUMBER OF BOLLS PER PLANT, NUMBER OF FLOWERS PER PLANT, AND PERCENTAGE OF BOLLS TO FLOWERS, IN THE SPRAYED AND UNSPRAYED PLOTS.

Manure.	Sprayed.				Unsprayed.		
	Plot.	Flowers.	Bolls.	Per cent. bolls.	Flowers.	Bolls.	Per cent. bolls.
No manure.	1 a	13	5	38·5	39	18	46·2
	1 b	25	10	40·0	49	16	36·7
	1 c	17	6	35·3	31	10	32·2
Nitrogen.	2 a	31	15	48·4	23	9	39·1
	2 b	37	16	43·2	52	24	46·2
	2 c	29	10	34·5	57	12	21·1
Phosphate.	3 a	22	9	40·9	42	15	35·7
	3 b	27	13	48·1	51	19	37·3
	3 c	38	11	28·9	44	16	36·4
Potash.	4 a	34	14	41·2	52	22	42·3
	4 b	39	14	35·9	55	24	43·8
	4 c	41	12	29·3	67	19	28·4
Phosphate and potash	5 a	24	10	41·7	32	13	40·6
	5 b	34	13	38·2	56	18	32·2
	5 c	41	12	29·3	60	16	26·7
Nitrogen, phosphate and potash.	6 a	22	9	40·9	58	22	40·0
	6 b	38	16	42·1	63	21	33·3
	6 c	32	13	40·6	59	21	35·6
Cotton-seed meal.	7 a	24	11	45·8	29	10	34·5
	7 b	27	11	40·8	33	15	45·5
	7 c	34	13	38·2	46	21	45·7
Cotton-seed meal, phosphate and potash.	8 a	39	19	48·7	62	25	40·3
	8 b	33	15	46·5	53	20	37·7
	8 c	39	15	38·5	58	21	36·2

REPORT ON THE PREVALENCE OF SOME PESTS AND DISEASES IN THE WEST INDIES DURING 1918.

(Compiled from the Reports of the principal local Agricultural Officers.)

This is the tenth report of this series, the latest previous one, that for 1917, appearing in the *West Indian Bulletin*, Vol. XVII, No. 2 pp. 83-106. The present report covers the period January to December 1918, and has been prepared in the same way as those for previous years, from information supplied by the Agricultural Officers in the several islands. Dr. J. C. Hutson continued as Acting Entomologist until July 12, when Mr. H. A. Ballou returned to Barbados and resumed the duties of his office.

ENTOMOLOGIST'S VISITS. The Entomologist visited Grenada at the end of the year in connexion with the work being done in that island in controlling thrips of cacao by spraying, and the general agricultural practices bearing on thrips control. An abstract of the report on this visit was published in the *Agricultural News* for April 19, 1919. (Vol. XVIII, p. 122.)

MYCOLOGIST'S VISITS. The Mycologist visited Dominica and Montserrat in September, and Grenada in October. In Dominica, the Mycologist was concerned with the investigation of certain points in connexion with root diseases, and in Montserrat with the occurrence of boll diseases of cotton.

The visit to Grenada had for its object an investigation into the so-called root disease of coco-nut trees. As a result of this visit the Mycologist was able to explain this affection of coco-nuts as due to the attacks of nematode worms, and not actually a root disease. The name 'red ring disease' is more descriptive. An account of this disease is to be found in the *Agricultural News* for December 14 and 28, 1918 (Vol. XVIII, pp. 398 and 414). At the request of the Government of Trinidad Mr. Nowell visited that colony in December 1918 and January 1919, for the purpose of studying the relation between the attacks of froghopper and root disease in producing the condition of sugar-cane known as blight. During this visit further knowledge of the nematode disease of coco-nuts was obtained.*

REMARKS ON CLIMATE.

AMOUNT AND DISTRIBUTION OF RAINFALL.

GRENADA. Richmond Hill observatory recorded 81·40 inches for 1918 as compared with the annual average of 72·20 inches for the previous five years, an increase of 9·20 inches. Generally, the rainfall was smaller than usual in August and the first half of September, and heavier than usual in June.

ST. VINCENT. Botanic Station, 119·19 inches, Experiment Station 99·27 inches. The rainfall was above the average, but was fairly well distributed. It was heavy towards the

(*Paper on this subject, *West Indian Bulletin*, Vol. XVII, No. 4.)

end of October and the beginning of November, and caused damage to cotton which had been planted in May and June.

ST. LUCIA. The rainfall at the Botanic Garden, Castries, the recording station of the northern end of the island, was 84·85 inches, this being ·80 inch less than the previous year. During the last three years there has been an average reduction in the annual precipitation of 7·83 inches. The rainfall at Réunion, the recording station at the south-west point of the island, was 63·47 inches, this being 2·08 less than the previous year. With the exception of the month of April when only 1·41 inches were registered, the distribution was very even, no appreciable difference being experienced between the usual 'wet' and 'dry' periods.

The heaviest fall of rain occurred in October, when 13·46 inches were recorded. Double figures were also registered in May, when 12 36 inches fell.

DOMINICA. The rainfall at the Botanic Garden was 71·64 inches or 9·16 below that of the previous year. On the Leeward Coast the rainfall was moderate and well distributed. There was also an absence of torrential rains. In the wet districts of the island the fall was below the average, a condition which is held to be a good augury of a large lime crop the following year.

A heavy squall was experienced on the evening of July 11, during which the wind blew with almost hurricane force for about twenty minutes, and high winds were experienced on August 22. Fortunately, but little damage was done. On the whole, the weather conditions were generally favourable throughout the year.

MONTSERRAT. There was a marked paucity in the rainfall until the end of August; exceptionally good rainfall in the month of February, but this was only at the leeward side of the island.

The rainfall for the various months of the year was as follows :—

January	2·67	inches
February	6·38	,,
March	3·89	
April	2·25	,,
May	3·01	,,
June	3·81	,,
July	3·45	,,
August	4·65	,,
September	7·85	,,
October	7·13	,,
November	5·30	,,
December	5·01	,,
Total	55·38	inches at the Botanic Station.

ANTIGUA The rainfall for the year at the Botanic Station was 39·89 inches, being about equal to that which fell during the previous year. The first four months of the year were dry. During May, a fair amount of rain fell, but the months of June, July and August were dry. November was the wettest month of the year, 7·7 inches of rain being measured at the Garden. On the whole, the past year has been unfavourable both for sugar-cane and cotton. Difficulty was experienced in establishing the latter crop during the months of June, July and August. In October and November very severe attacks of cotton caterpillars were experienced, and showery weather washed off the insecticide applied for their control almost as soon as it was put on. Flower-bud maggot appeared in October and did some damage to late planted cotton.

ST. KITTS. The total rainfall for the year 1918 at the Experiment Station, La Guérite, was 49·35 inches. From January to August 31, eight months, 23·08 inches ; from September to December, four months, 26·27 inches. The drought during the first eight months seriously affected the sugar crop, which will be much below the average. The heavy rains at the end of the year caused much loss to the late cotton.

NEVIS. The total rainfall for the year from January 1 to December 31, 1918, was 53·98 inches, which is 9·88 inches more than that of last year. The rainfall per quarter is as follows:—

Quarter ending March 31	8·26 inches	
" " June 30	10·75	"
" " Sept. 30	15·41	"
" " Dec. 31	19·56	"
	53·98 inches	

BRITISH VIRGIN ISLANDS. Rain fell in measurable quantity on 190 days of the period January 1 to December 31, 1918, the total amount recorded at the Experiment Station being 52·55 inches, as compared with 52·83 inches, the average for the previous seventeen years. The rainfall was poorly distributed, the months of May, June, September, October and November all having more or less over the average, the other months decidedly less than the average.

ABNORMAL OCCURRENCES (PERIODS OF DROUGHT, WET WEATHER, WIND).

GRENADA. Shortage of rain in August and September was associated with unusual attacks of aphis on eddoes, tannias, and corn, and was followed by a late cacao crop which promises to be smaller than usual in some parts.

ST. VINCENT. Heavy weather was experienced on August 22, and the high wind which accompanied it damaged early planted cotton

ST. LUCIA. On August 22, between 2 p.m. and 3 p.m., the barometer dropped two tenths rapidly to 29·8, where it remained stationary for some time before rising. The wind blew in very strong gusts from south-east. The average velocity of the wind from 2 p.m. to 3 p.m. was 28 miles. Some of the individual gusts registered a velocity of 45 to 50 miles. A few trees were overturned. On September 9 further indications showed a storm passing to the North. The barometer fell slowly to 29·8, and the wind blew strongly from the South with heavy showers.

MONTSERRAT. Except the low rainfall until September, there was nothing abnormal about the weather conditions throughout the year.

ST. KITTS. Period of drought for the first eight months of the year. Good rainfall during the last four months.

NEVIS. The early part of the year was dry, being a continuation of the drought which began in October 1917. The rainfall for the quarter ending December 31, 1917, was only

9·20 inches. The latter part of the year was fairly wet, 34·97 inches of rain being recorded for the period July 1 to December 31, against 19·01 from January 1 to June 30.

The year was practically calm, and no damage was done to crops on account of high winds.

BRITISH VIRGIN ISLANDS. Earthquake shocks were felt on February 2, and October 14 and 23. Indications pointed to the passing of cyclonic disturbances, more or less remote, on August 23 to 24, September 9 to 10, and 29. None was sufficiently near to cause damage. Heavy rains fell on November 6 (2·07 inches in 1 hour 20 min.), and on November 9 (4·06 inches in 7 hours).

INFLUENCE OF WEATHER ON CROPS.

ST. VINCENT. The year, on the whole, was a satisfactory one for crops, except for the occurrences mentioned above.

ST. LUCIA. The even distribution of the rainfall prevented loss of crops through drought, and lime seedling nurseries were not destroyed by damping off fungus.

MONTSERRAT. Taking the island as a whole, the low rainfall in the months of May, June and July had undoubtedly a bad effect on the cotton crops. This would seem to apply particularly to the lands in poor condition in many of the outlying districts, the cultivations of which are in the hands of peasant proprietors, and give very poor cotton crops.

ST. KITTS. All crops were seriously affected by the drought in the first eight months of the year, and at the end of August there was little prospect of more than half the average sugar crop. The late rains have much improved the position of affairs. Ground provisions, corn and other crops were much affected.

NEVIS. On account of the drought during the early part of the year, great difficulty was experienced in getting the cane crop established, and supplying had to be continued in many places till as late as April. In some places where early cotton is usually planted, similar difficulty was experienced in getting the crop established, and generally speaking, the crop was a late one Heavy rains fell during the latter part of the year, which did a considerable amount of damage to the cotton crop throughout the island. On the other hand, these rains were the salvation of the cane crop, and the improvement in some places was simply marvellous.

BRITISH VIRGIN ISLANDS. The cotton crop was seriously affected by the lack of rain in July and August. The rainfall for the two months was 4·17 inches below the average.

PART I.—INSECT PESTS.

SUGAR-CANE.

MOTH BORER (*Diatraea saccharalis*).

GRENADA. No reported instances of serious injury to canes.

ST. VINCENT. The attacks were generally much less severe than in the previous year.

ST. LUCIA. On naturally drained lands and in mixed cultivation in small holdings.

MONTSERRAT. Severe in certain districts only, but generally present throughout the island.

ANTIGUA. Generally present in all cane fields.

ST. KITTS. This pest can be found in every cane field, but cannot be said to be more severe during the past season.

NEVIS. The moth borer was present throughout the island, causing an appreciable amount of damage, especially to ratoons. Guinea corn is grown fairly largely on some estates as a wind-break for cotton, and this crop is more or less severely attacked by the moth borer, which no doubt accounts for the prevalence of this pest, as the Guinea corn is generally left standing until the fields are again being prepared for planting, thus allowing the moths time to hatch out.

BRITISH VIRGIN ISLANDS. Not observed.

WEEVIL BORER (*Metamasius sericeus*).

ST. LUCIA. Generally present but not serious.

ANTIGUA. Generally present in all cane fields.

ROOT BORER (*Diaprepes abbreviatus*, and varieties).

ST. LUCIA. Generally present but not serious.

ANTIGUA. No observations made during the year.

ST. KITTS. These cannot be said to be a serious source of loss throughout the island, but in special districts they do exist to the detriment of the crop.

BRITISH VIRGIN ISLANDS. Less plentiful than in some previous years. The adults are preyed upon to a small extent by the Chitty Bird or Grey King Bird (*Tyranus dominicensis*).

ROOT BORERS (*Diaprepes famelicus*, *Exophthalmus esuriens*).

ST. KITTS. The beetles can be found in almost all cane fields on the growing cane, and on one estate systematic catching of them is carried on, but there does not appear to be any serious loss from them.

NEVIS. Adult insects observed in the neighbourhood of cane fields, but no damage observed to be done by the grub.

ST. LUCIA. Found only in dead canes.

ANTIGUA. Periodically seen on light lands, but not responsible for damage.

ST. KITTS. There has been no report of any damage by termites during the year, and the Pond estate seems free of them.

BRITISH VIRGIN ISLANDS. Termites generally distributed; not recorded as doing any particular damage to crops.

HARD BACK GRUBS.

ANTIGUA. Common on heavy lands in central part of the island; responsible for considerable damage to cane crop. During latter period under review, some planters attempted to control the pest by trap crops. On one estate 125,000 were destroyed in a short space of time.

NEVIS. *Ligyrus tumulosus*, both adult and grub, found in field during preparations. This insect is fairly abundant throughout the island, but no damage done by it was observed.

OTHER INSECTS ATTACKING SUGAR-CANE.

GRENADA. Froghopper (*Tomaspis saccharina*) is known to occur in the island, but there are no reported observations of its attacks: apparently not very troublesome.

ST. LUCIA. Mealy-bug common in cane fields, especially in unmanured areas. Various grasshoppers are well distributed and do minor damage to young cane foliage. There is also a small bettle which does a fair amount of damage to young canes.

ST. KITTS. Grasshoppers attack the young shoots of the canes and do much damage in the dry season.

NEVIS. The grasshopper did a fair amount of damage to young canes.

COTTON.

COTTON WORM (*Alabama argillacea*).

ST. VINCENT. No serious attack reported.

MONTSERRAT. Attacks were normal on the first crop, but became very severe in certain districts on the second growth in the months of October and November. Very considerable areas were entirely defoliated, as the promise of a second crop was not considered worth the expense of applying the necessary poison.

ANTIGUA. Very severe attacks were experienced during the latter end of the year. Considerable damage was done to plants: this was pronounced in connexion with cotton grown by peasants.

ST. KITTS. The cotton worm was very severe in its attacks during the past season, and large quantities of poison, Paris green and London purple, were used.

NEVIS. The cotton worm was very severe in its attacks during the early part of the season, causing a considerable amount of damage to many fields. Much of the damage done is due to planters not having a sufficient supply of poison on

hand, and to the use of poison which was mixed far too weak to be effective. The attack started during the latter part of July, and was most severe during September and the early part of October, falling off toward the end of October, and ceasing altogether during November.

BRITISH VIRGIN ISLANDS. Severe attacks in all districts late in the year.

BOLL WORM (*Heliothis armgier*)
and
CORN EAR WORM (*Laphygma frugiperda*).

MONTSERRAT. Not known to attack cotton in this island.

ANTIGUA. Boll worm was noticed during the year, but did practically no damage.

ST. KITTS. A few instances of corn ear worm attacks were found during the year but no serious damage resulted from them.

NEVIS. The corn ear worm was observed in many parts of the island doing a great deal of damage to green bolls.

COTTON STAINERS (*Dysdercus* spp.).

GRENADA. Plentiful on Sea Island cotton.

ST. VINCENT. These occurred in certain localities where cotton was planted early. The damage caused by the pest was small, and large areas were free of the pest throughout the year.

MONTSERRAT. Attacks were locally severe early in the season' and stainers were more generally abundant at the end of November than in years past. Considered in numbers at near the close of the year to be a month ahead of previous years, a circumstance judged to be attributable to the more general fruiting of silk-cotton trees early in the season. At the close of the year *D. andreae* predominated to the extent of 100 to 1 of *D. delauneyi*.

ANTIGUA. Stainers appeared much earlier during the season than in former years. They rapidly increased, and were the cause of much internal boll disease.

ST. KITTS. Cotton stainers have been very plentiful and very destructive during the past season; flights of them have been observed. Legislation has been enforced for the destruction of their native food-plants.

NEVIS. Cotton stainers were observed in large numbers as early as August this year. Never before have they been observed in such large numbers, causing such a high percentage of stained cotton and wholesale shedding of bolls. This insect is now regarded as the most serious pest of cotton.

BRITISH VIRGIN ISLANDS. Sporadic attacks.

BUSH BUGS (*Nezara viridula*, and others).

GRENADA. Observed on Sea Island cotton.

ST. VINCENT. No severe attacks recorded. Eggs generally heavily parasitized.

ST. LUCIA. Not abundant, but usually found in cotton patches.

MONTSERRAT. Bush bugs have never been noticed to attack cotton plants severely in this island, but are undoubtedly responsible for part of the stained cotton reaped from the first crop of cotton when it is not infested with cotton stainers.

ANTIGUA. Noticed in most cotton fields. These insects are, on account of their colour, difficult to detect, and possibly more exist than is realized. The number observed, however, was not great.

BRITISH VIRGIN ISLANDS. *Nezara viridula* was suspected of infecting cotton growing at the Station with internal boll disease.

BLACK SCALE (*Saissetia nigra*), WHITE SCALE (*Hemichionaspis minor*).

ST. VINCENT. Black scale occurs in the Leeward district, but damage to cotton is not extensive.

MONTSERRAT. Black scale was perhaps more prevalent than usual late in the season ; it is not regarded as a cotton pest in this island.

ANTIGUA. Seen on old cotton, did but little damage.

ST. KITTS. Cotton plants are not left on the land long enough to be troubled by these pests.

NEVIS. Both the black and the white scale were observed in fields of cotton during the latter part of the year.

BRITISH VIRGIN ISLANDS. Not recorded as attacking cotton. Probably white scale attacks the perennial types of cotton.

FLOWER-BUD MAGGOT (*Contarina gossypii*).

ANTIGUA. Noticed during October. Attack increased during the following month, and slightly decreased in December. The amount of damage done by this pest is difficult to estimate, but was not inconsiderable to late planted cotton.

BRITISH VIRGIN ISLANDS. Not recorded during the year : probably present.

LEAF-BLISTER MITE (*Eriophyes gossypii*).

GRENADA. Not recorded on Sea Island cotton. An unidentified species, thought to be *gossyppii*, was found in abundance on *Malachra* sp., probably *capitata*, which is plentiful in the Morne Rouge district.

ST. VINCENT. No severe attacks recorded, although seen in many places.

ST. LUCIA. Found wherever cotton is grown, and generally serious. In the new Sea Island cotton trial plots at Balambouche and O'Cap estates, this insect is also becoming a very serious pest.

MONTSERRAT. More prevalent than for many years, due to the carelessness in destroying old cotton plants from the previous crop. Considerable losses on certain areas as the result of attacks, chiefly on lands of small holders. There may possibly be a correlation between its prevalence and the very dry season experienced. There need be no concern about attacks from leaf blister mite so long as no old plants exist on the ground at planting time.

ANTIGUA. Commonly found in cotton fields. No great increase in severity has taken place during the year.

ST. KITTS. This pest has also been very prevalent during the past season. A close season for cotton has been established by law, which should do much to eradicate this pest.

NEVIS. Not so plentiful as in past years, and very little damage done to the cotton crop by the pest.

BRITISH VIRGIN ISLANDS. In practically all cotton fields.

OTHER INSECTS ATTACKING COTTON.

ANTIGUA. One field early in May was severely attacked by aphis, but subsequently recovered.

CACAO.

THRIPS (*Heliothrips rubrocinctus*, Giard.).

GRENADA. Locally severe, but not so generally severe as in 1916, and not considered worse than in 1917. Some control by spraying has been effected, according to planters' reports.

ST. VINCENT. No serious attack recorded.

ST. LUCIA. Locally severe, particularly on low land and damp hillsides. This insect attacks various plants, including guava, mango, almond, cashew, and cassava. It was particularly serious during the year.

DOMINICA. Present, but no great amount of damage caused by them.

ST. KITTS. This pest was seen on cacao on Molineux estate, but has been lessened by cutting away the shade trees, and giving more light to the plant. No actual damage occurred.

BEETLE (*Steirastoma depressum*, L.).

GRENADA. Chiefly on the western side of the island.

SCALE INSECTS AND MEALY-BUGS.

GRENADA. Mealy-bug, probably *Pseudococcus citri*, on cacao pods, and *P. nipae* on backs of cacao leaves.

ST. LUCIA. Mealy-bug found on young pods and leaves.

DOMINICA. Mealy-bugs occasionally met with on cacao trees. Usually found clustered around the stem of young pods.

OTHER INSECTS ATTACKING CACAO.

GRENADA. A small caterpillar about ½ to ¾-inch long eats holes in young leaves.

Limes and other Citrus.

SCALE INSECTS.

GRENADA. The following occur: *Lepidosaphes beckii, Chionaspis citri, Coccus viridis, Selanaspidus articulatus.*

ST. VINCENT. All citrus plants severely attacked, and limes becoming increasingly scarce. Few plantations have been destroyed.

ST. LUCIA. *Chionaspis citri* generally present, especially in dry districts. *Saissetia nigra* found in fields where ochroes have been grown. *Coccus viridis* generally present; severe on seedlings in nurseries. *Selenaspidus articulatus* generally present on lime leaves, apparently doing little damage. *Lepidosaphes beckii* generally distributed; severe, especially where cultivation is poor.

DOMINICA. These are to be found throughout the island. The best means of keeping them under control is by maintaining the trees of the plantation in vigorous health. To this end, the spending of money in draining and manuring, and providing shelter-belts is more productive of good than the costly efforts in attempting to spray trees.

MONTSERRAT. The damage resulting from the attacks of scale insects (chiefly purple scale) not more pronounced than usual. Area in limes gradually being reduced on account of the die-back usually accompanied by attacks of purple scale. Green scale was less prominent than usual, and there have been no severe attacks of the Lantana bug.

ANTIGUA. Scale insects common on all lime plantations.

NEVIS. The purple and the green scale were observed in all the lime plantations in the island. The purple scale in particular has done a great deal of damage to limes.

BRITISH VIRGIN ISLANDS. Snow scale (*Chionaspis citri*), and *Lecanium hemisphericum* are common on lime trees.

BARK BORER (*Leptostylus praemorsus*).

ST. LUCIA. Particularly in the northern end of the island. It is not severe, and is kept fairly under control.

DOMINICA. Reported in one instance.

NEVIS. Not observed.

TWIG BORER (*Elaphidion mite*).

ANTIGUA. Not noticed during the year.

NEVIS. Not observed.

ROOT BORERS, ROOT GRUBS (*Diaprepes* spp.), striped and black.

GRENADA. The striped, and an almost white one, damage lime leaves and twigs.

ST. LUCIA. *Diaprepes abbreviatus*, var. is fairly well distributed, but damage to roots uncertain.

ANTIGUA. No observations made during the year.

NEVIS. Not observed.

BRITISH VIRGIN ISLANDS. The larvae of *Diaprepes abbreviatus spengleri* caused considerable damage to young trees; the adults eat the foliage and young twigs.

OTHER INSECTS ATTACKING CITRUS.

ST. LUCIA. Weevil (*Neocyphus pudens*) found attacking limes in the Soufrière district.

SWEET POTATOES.

SCARABEE (*Euscepes Cryptorhynchus batatae*, Waterhouse).

MONTSERRAT. Nearly always present when potatoes are reaped, but most plentiful when the crop is older than five months.

ANTIGUA. Increased number of potatoes attacked by this pest. This is probably accounted for by the increased area planted.

NEVIS. Fairly abundant on certain estates. The cultivation of sweet potatoes had to be abandoned on a certain estate on account of this pest.

CATERPILLARS (*Protoparce cingulata*, Fabr., and others).

ST. LUCIA. Caterpillars are serious at certain seasons.

MONTSERRAT. Not known as a pest in this island.

ANTIGUA. Rather common during the latter end of the year. Did not apparently affect yields.

NEVIS. Not very plentiful; found here and there in very small numbers.

BRITISH VIRGIN ISLANDS. Severe attacks in the autumn months.

THRIPS.

ANTIGUA. Not noticed.

NEVIS. Not observed.

RED SPIDER (*Tetranychus telarius*, Linn.).

ANTIGUA. Noticed in some few localities.

NEVIS. Not observed.

OTHER INSECTS ATTACKING SWEET POTATOES.

GRENADA. Slugs (leather jackets) locally severe.
Bush bugs generally distributed, but damage, if any, not observed.

ST. LUCIA. The common slug does considerable damage to newly planted cuttings especially on wet lands.

MONTSERRAT. The only potato pest attacking the leaves of this crop in the island is *Sylepta helcitalis*, which is very general, though seldom severe.

ST. KITTS. As far as is known, sweet potatoes have not been troubled by any insect pest.

NEVIS. None.

Ground Nuts.

LEAF-EATING CATERPILLARS.

ST. LUCIA. Generally present.

OTHER INSECTS ATTACKING GROUND NUTS.

ST. KITTS. The ground nuts grown at the Experiment Station and in one district of the island have been free of any insect pest as far as is known.

Coco-nuts.

WEEVIL (*Rhyncophorus palmarum*).

GRENADA. In all stages of development in the younger portion of stems of trees dying from root disease, also in one instance in a Latana palm dying with no evidence of root disease.

ST. LUCIA. Rarely met with.

NEVIS. Not observed.

WHITE FLY (*Aleyrodicus cocois*).

ST. LUCIA. Present everywhere; not serious.

DOMINICA. Present, but not causing much injury.

NEVIS. Not observed.

SCALE INSECTS (*Aspidiotus destructor*, and others).

ST. LUCIA. Fairly serious on young trees during dry spells in dry situations, and in sandy soils along the coast. *Diaspis boisduvalii* also present in situations similar to those mentioned above, and fairly serious.

DOMINICA. Present, but no serious injury recorded.

ANTIGUA. Generally present; does little apparent damage.

NEVIS. Found throughout the island, but attacking the older branches. Not regarded as a serious pest.

BRITISH VIRGIN ISLANDS. Occasionally severe on young palms.

Indian Corn.

CORN EAR WORM (*Heliothis armiger*, and others).

ST. LUCIA. Is generally distributed.

ANTIGUA. Invariably present.

ST. KITTS. The young Indian corn suffers greatly from this pest.

NEVIS. Very abundant during the early part of the year.

BRITISH VIRGIN ISLANDS. Locally severe. The attacks seem to be especially severe in the autumn months.

BOLL WORM (*Laphygma frugiperda*, and others).

ANTIGUA. Common during certain parts of the year. Was responsible for some damage.

NEVIS. Not observed.

HARD BACK GRUBS.

ANTIGUA. Grubs of *Lachnosterna* sp. cause a very considerable amount of damage to the corn crop in certain localities. Responsible for total failure in some fields.

ST. KITTS. No incidence of loss by hard backs found.

NEVIS. Not observed attacking corn.

OTHER INSECTS ATTACKING INDIAN CORN.

GRENADA. *Cydosia histrio* is recorded.

ST. LUCIA. Grain weevils were generally distributed and attacked the corn while ripening in the field, as well as when stored.

ONIONS.

CATERPILLARS, CUT WORMS.

ANTIGUA. Invariably present in onion fields. Were not responsible for much damage where normal amount of care was taken.

NEVIS. Observed only in nursery beds; general crop was not attacked this season.

BRITISH VIRGIN ISLANDS. Onions in all districts suffered from severe attacks of caterpillars early in the year. Where domestic fowls had access to the plots, the onions suffered less. Hand picking appeared to be the only effective remedy other than the above.

THRIPS (*Thrips tabaci*).

ANTIGUA. Common in all fields, and responsible for a very considerable amount of damage during the year under report.

NEVIS. More abundant this year, probably on account of the unfavourable weather under which the crop was grown.

YAMS.

SCALE INSECT (*Aspidiotus hartii*).

MONTSERRAT. The yams reaped at the Experiment Station at the close of 1918 were comparatively free from attacks of scale insects. No observations elsewhere.

ANTIGUA. Generally present.

ST. KITTS. Attacks stored yams.

NEVIS. Not observed.

OTHER INSECTS ATTACKING YAMS.

DOMINICA. The tubers are sometimes attacked by a borer.

GREEN DRESSINGS, BEANS AND PEAS.

LEAF-EATING CATERPILLARS.

GRENADA. *Anticarsia gemmatalis* is recorded on *Canavalia ensiformis*.

MONTSERRAT. Leaf-eating caterpillars were not prominent during the year, and were perhaps less prevalent than

usual. Green dressing crops do not as a rule suffer severely from caterpillars, though Bengal beans are occasionally eaten down.

ANTIGUA. Very severe attacks were experienced during October and November.

ST. KITTS. These have been very prevalent and destructive during the past year on pigeon peas, horse beans, and cowpeas.

BUSH BUGS (*Nezara viridula*, and others).

MONTSERRAT. Nezara bugs are usually found attacking all kinds of bean crops, and one instance occurred during the year of severe damage to a crop of cowpeas.

ANTIGUA. No record.

BRITISH VIRGIN ISLANDS. *Nezara viridula* was common on peas and beans grown for food—not green dressing. The growing of green dressings is not practised in the British Virgin Islands.

OTHER INSECTS ATTACKING THESE CROPS.

GRENADA. Red spider on *Crotalaria usarmoensis* at the Botanic Garden, but did not attack other adjacent species.

ST. KITTS. Grasshoppers do much damage at times to the young shoots.

BANANAS AND PLANTAINS.

BLACK WEEVIL BORER (*Cosmopolites sordidus*).

GRENADA. Collected on traps set at the Botanic Garden. Not yet recorded on traps or otherwise from other parts of the island.

ST. LUCIA. Throughout the island; damage done particularly during the dry season. The spread of this insect is materially aided by neglect in examining suckers taken from infested areas to new plantations.

DOMINICA. Attacks both plantains and bananas, the former severely, the latter lightly.

ANTIGUA. Found on one plantation in the southern part of the island. Probably responsible for a certain amount of damage.

NEVIS. Not observed.

BROWN WEEVIL BORER (*Metamasius sericeus*, Oliv.).

NEVIS. Not observed.

LARGE BLACK HARD BACK BORER OR BANANA BORER (*Tomarus bituberculatus*).

ST. LUCIA. Particularly during spring and the beginning of the rainy season. This pest is spread in the same way as the black weevil borer.

NEVIS. Not observed.

TANNIAS, DASHEENS AND EDDOES.

BANANA BORER (*Tomarus bituberculatus*).

ST. LUCIA. Particularly during the spring season and beginning of the wet season. Retards the growth and general development of the plant, and sometimes destroys the plant completely.

OTHER INSECTS ATTACKING TANNIAS, DASHEENS AND EDDOES.

GRENADA. Aphis severely infested eddoe and tannia leaves in St. Andrews during a spell of dry weather in August. Spraying with Black Leaf 40 and soap water was very effective in destroying them.

GENERAL REMARKS.

MISCELLANEOUS INSECTS NOT OTHERWISE PROVIDED FOR.

GRENADA. *Aspidiotus destructor* occurred on sugar-apple, causing the shedding of mature leaves on one tree.

ST. LUCIA. The mole cricket (*Gryllotalpa didactyla* ?) is a common pest to garden vegetable crops, especially cabbage, tomato, lettuce, etc., and it is difficult to control this pest.

MONTSERRAT. Pods of *Datura metel* were discovered to be infested with the bug *Phthia picta*. This may account for the poor germination of the seeds of this plant when sown. Seedlings of ajowan (*Carum copticum*) were severely damaged by caterpillars of *Prodenia* sp. A small green leaf-hopper, attacking plants of cowpea, is suspected of causing injury.

ANTIGUA. Mahogany twig borer attacked mahogany trees on several occasions during the year. No material damage was done.

ST. KITTS. Grasshoppers are a great source of damage to the young growing cane crop.

NEVIS. None.

BRITISH VIRGIN ISLANDS. *Batocera rubus* continues to spread. The insect has lately been observed at Virgin Gorda. It is gradually killing all the wild figs (*Ficus laurifolia* ?).

NATURAL ENEMIES OF INJURIOUS INSECTS.

PARASITIC AND PREDACEOUS INSECTS.

BRITISH VIRGIN ISLANDS. No 'Jack Spaniards' have been observed in Tortola since the cyclone of 1916. A few nests have been seen on Virgin Gorda and Anegada.

OTHER REMARKS.

GRENADA. Nematode worms occur in various parts of the island in the roots of bluggoes, bananas, and coco-nuts, causing considerable losses in a few recorded instances.

ST. KITTS. Insects, such as cotton worms, caterpillars, and cotton stainers have been more destructive this year than for many seasons.

NEVIS. Except for the cotton stainer and the cotton worm, the crops, on the whole, were free from any insect pests.

PART II.—DISEASES OF ECONOMIC PLANTS.

CACAO.

ROOT DISEASES (*Rosellinia* spp.).

ST. LUCIA. Occurred particularly in the Soufrière district where it is well distributed and severe in many plantations. Control measures are undertaken in most plantations.

CANKER (*Phytophthora Faberi*, Maubl.).

ST. LUCIA. Met with in plantations generally, but not very serious. On the larger estates it is kept under fair control.

DOMINICA. Generally distributed. It is particularly fatal in the case of the finer grades of cacao. The Criollo type of cacao is now seldom met with, as it cannot long survive the attacks of canker. The Forastero and Calabacillo varieties are much more resistant.

BLACK ROT OF PODS (*Phytophthora Faberi*).

ST. LUCIA. Low situations suffer generally during the wet season. Control measures are undertaken in the larger plantations.

DOMINICA. Chiefly found on the pods of Criollo and Alligator cacao.

BROWN ROT OF PODS (*Diplodia Theobromae*, Pat.).

ST. LUCIA. When wet weather occurs in the crop season this disease is particularly serious in low situations where drainage is imperfect. Rats help considerably in spreading it.

DOMINICA. Present, but not usually severe.

DIE-BACK AND STEM DISEASE (*Diplodia Theobromae*).

ST. LUCIA. Generally bad: more serious in low situations and exposed windy hillsides.

DOMINICA. Usually the result of exposure to wind.

THREAD BLIGHTS.

ST. LUCIA. Met with in plantations bordering forest areas.

HORSE-HAIR BLIGHT.

GRENADA. Occurs in wet localities.

OTHER DISEASES, OR GENERAL REMARKS.

ST. KITTS. There is only a small cultivation of cacao on the island, and this is fairly free from disease.

COCO-NUTS.

BUD ROT.

ST. LUCIA. Distributed to a limited extent, and receives practically no attention.

ANTIGUA. Not noticed.

NEVIS. A sporadic case occurred on a certain plantation.

ROOT DISEASE.

ANTIGUA. Probably exists in several localities.

OTHER DISEASES, OR GENERAL REMARKS.

GRENADA. 'Little Leaf' disease occurs periodically. *Diplodia* sp observed on petioles of a tree at Westerhall Experiment Plot.

ST. KITTS. There are no coco-nut cultivations on a commercia scale on the island, but the trees growing in differen localities appear healthy.

NEVIS. Plantations throughout the island are fairly healthy.

TANNIAS, DASHEENS, EDDOES.

DISEASES OF, OR REMARKS.

There has been no record of any disease during the year.

INDIAN CORN.

RUSTS (red or brown).

ST. LUCIA. Brown rust is fairly common on corn planted out of season, resulting in very poor yield.

ANTIGUA. Fairly common, but does not seem to affect the crop

SMUT.

GRENADA. Not serious.

ANTIGUA. Isolated instances found.

ST. KITTS. Instances of this disease can be found generally abou the corn fields, but not to any extent.

NEVIS. Occurred throughout the island, but not causing seriou damage.

ROOT DISEASE.

ST. KITTS. The corn crop has been very poor this season, due in a great measure to the drought, but root disease is also liable for a good deal of the shortage.

IMPHEE AND GUINEA CORN.

RUSTS.

GRENADA. Leaf rust occurred.

NEVIS. Occurred to a fairly great extent throughout the islan d

ST. KITTS. Not cultivated to any extent.

COTTON.

SOFT ROT OF BOLLS (*Phytophthora* sp.).

MONTSERRAT. Less prevalent than usual; considered due to the dry season.

ST. KITTS. Attacks were occasioned by the heavy rains in the latter part of the season.

WEST INDIAN LEAF MILDEW.

GRENADA. Occurred on Sea Island cotton.

ST. VINCENT. General, late in season.

MONTSERRAT. More common on the second growth in November and December, but never severe.

ANTIGUA. Prevalent in cotton fields late in the season.

ST. KITTS. This appeared at the end of the season, but caused little damage.

NEVIS. Occurred to a fairly great extent in nearly all fields toward the latter part of the year.

BRITISH VIRGIN ISLANDS. Probably present.

BACTERIAL BOLL DISEASE (external).

GRENADA. A disease of the boll - external - causing black, sunken, hard surfaced patches observed on Sea Island cotton.

MONTSERRAT. Extremely rare in the 1918 season.

NEVIS. Very abundant during the latter part of the year, causing great damage.

ANGULAR LEAF SPOT.

ST. LUCIA. Present to a small extent in new trial plots of Sea Island cotton at Balambouche estate.

NEVIS. Observed throughout the island toward the end of the cotton season.

INTERNAL BOLL DISEASE.

ST. VINCENT. No serious damage by this disease was recorded. Local infestation occurred in places where cotton stainers attacked early planted plots.

ST. LUCIA. Observed in new trial plots of Sea Island cotton at Balambouche estate.

MONTSERRAT. Common generally on cotton-stainer infested plants. On one estate in particular, the damage from cotton stainers was so severe as to ruin entirely the second crop, which otherwise was extremely promising.

ANTIGUA. Observed throughout the island towards the latter part of the year. Much more severe than in previous years. Stainers made their appearance in the cotton fields very much earlier than in previous years.

ST. KITTS. Owing to the great increase in the number of cotton stainers, there has been a great increase in this disease, especially in the latter part of the season.

NEVIS. Very abundant this year on account of the large number of stainers.

BRITISH VIRGIN ISLANDS. Recorded from the Experiment Station, and probably generally distributed.

OTHER DISEASES OF COTTON, OR GENERAL REMARKS.

ANTIGUA. Some fields received indifferent cultivation, and in many the cotton plants were planted too far apart.

ST. KITTS. The earlier planted cotton was singularly free from pests, and gave good returns. The later planted was affected by the heavy rains and attacks of cotton stainers.

NEVIS. The cotton crop throughout the island has been very badly damaged on account of the severe attacks of cotton stainers, causing shedding of bolls and stained cotton.

Ground Nuts.

LEAF RUST (*Uredo arachidis*, Lagh.).

ST. LUCIA. Generally distributed, especially on wet land.

MONTSERRAT. Attacks of leaf rust in the Experiment Station were normal. Practically no other cultivation in the island.

OTHER DISEASES OF GROUND NUTS, OR GENERAL REMARKS.

ST. KITTS. The ground nuts under cultivation seem free from disease.

Limes and other Citrus Trees.

BLACK ROOT DISEASE (*Rosellinia* spp.).

DOMINICA. The position under this head needs a thorough investigation. Owing to depletion of the staff during the past eighteen months, it has not been possible to do this locally. Owing to the hurricanes of 1915 and 1916, a new situation has arisen in this connexion which requires careful study in the field. Meanwhile, the disease continues to take its toll of trees on estates in forest districts.

UNIDENTIFIED ROOT OR COLLAR DISEASES.

GRENADA. Collar rot local in southern extremity of island, chiefly on land insufficiently drained.

DOMINICA. Collar rot occurs in the case of seedling orange trees. The trees appear to be susceptible to attacks when about twenty-five years of age.

DIE-BACK.

GRENADA. Local, associated with scale insect infestation.

ST. LUCIA. Noticeable on low, badly drained heavy lands.

DOMINICA. The result of exposure to wind, to lack of plant food in the soil, to attacks of scale insects, or to decay of wood of the branches owing to injuries or bad pruning, and in part to an unbalanced system of manuring. Can be largely controlled by sound methods of agriculture.

MONTSERRAT. Die-back is very common on scale-infested trees.

SEEDLING DISEASES.

GRENADA. Damping off, local.

DOMINICA. Occurs every season in the seed beds. It is easily controlled by dusting the plants with a mixture of equal parts of sulphur and finely sifted lime, if action is taken on the first sign of disease.

MONTSERRAT. Damping off disease very prevalent in showery weather. Bordeaux mixture is found to be fairly reliable as a preventive.

SUGAR-CANE.

ROOT DISEASE (*Marasmius Sacchari*, Wakker, and allied species.

ST. LUCIA. Generally severe, particularly on the Bourbon variety.

ANTIGUA. Some fields severely attacked during the year. Noticed in practically all fields throughout the island.

ST. KITTS. The effects of the drought in the early part of the season were more marked than this disease, and since the rains, the canes have wonderfully recovered. Damage has only been done in certain districts.

NEVIS. Occurred to a fairly great extent throughout the island. B. 147 is particularly susceptible to this disease.

BRITISH VIRGIN ISLANDS. Probably present in most cultivations.

RIND FUNGUS (*Melanconium Sacchari*, Massee.).

ST. LUCIA. General : occurs particularly in large patches on low ground.

ANTIGUA. Common throughout the island.

NEVIS. Observed on a few estates, but not occurring to any great extent.

PINE-APPLE DISEASE (*Thielaviopsis ethaceticus*).

ST. LUCIA. Common in patches under peasant cultivation.

ST. KITTS. This can be found in cuttings of canes used for planting.

OTHER DISEASES OF SUGAR-CANE, OR GENERAL REMARKS.

ANTIGUA. Labour troubles, and the scarcity of some kinds of agricultural implements were the cause of a number of fields receiving sufficient cultivation. In addition, an indifferent growing season was experienced.

ST. KITTS. There has been no epidemic of sugar-cane diseases during the year and, as mentioned above, the canes have recovered remarkably since the rains.

SWEET POTATOES.

ANTIGUA. A white fungus noticed on many tubers, but apparently does little or no damage.

OTHER DISEASES OF SWEET POTATOES.

ST. KITTS. The sweet potatoes were much affected by the drought, but there has been no serious trouble owing to disease.

Bananas and Plantains.

OTHER DISEASES, OR GENERAL REMARKS.

GRENADA. Nematodes (*Tylenchus musicola*, Cobb.) in roots and rhizomes of bluggoes mostly, and Chinese banana slightly, local.

Onions.

BACTERIAL ROT.

MONTSERRAT. Bacterial rot was less prevalent than in the previous year, which was probably due to the much drier season in which the onions were developed.

ST. KITTS. Onions are not cultivated on a commercial scale, and are used rapidly after reaping.

BRITISH VIRGIN ISLANDS. Stored onions suffered from a rot, possibly bacterial rot, but no rot of this description was observed in the plots.

OTHER DISEASES OF ONIONS.

GRENADA. A disease producing a black powdery appearance between the leaf-base layers in stored onions grown at the Botanic Gardens was observed.

Fungi Parasitic on Insects.

ON SCALE INSECTS.

GRENADA. *Cephalosporium lecanii* was generally distributed, *Myriangium duriaei* and *Ophionectria coccicola* occurred locally, while *Sphaerostilbe coccophila* was generally distributed.

ST. LUCIA. The four common species occurred as usual.

DOMINICA. The five species continued their activities as usual.

ANTIGUA. Red-headed fungus fairly common. No observation in connexion with others made.

ON ANY OTHER INSECT.

GRENADA. *Sporotrichum globuliferum* on cacao thrips occurred locally.

ST. KITTS. Fungus *Botrytis rileyi*, Farlow, attacking caterpillars on leguminous plants on Stapleton estate.

Phanerogamic Parasites.

LOVE VINE.

GRENADA. Locally severe on wild plants.

ST. LUCIA. Shows a tendency to increase. Attempts to destroy it are generally made with an apparent lack of knowledge of its habit of growth. Except on hedges, it is seldom met with on cultivated plants.

DOMINICA. Still reported to be spreading to new localities. Copies of law in force in Grenada and Barbados have been placed before the Government, with a view to enactment of similar legislation in this island.

MONTSERRAT. It is suspected that love vine is attacked by a fungus, specimens of which have been submitted for examination. No concern is felt in regard to infestation of plants by love vine, and attacks are chiefly confined to wild, useless plants, or small trees.

ANTIGUA. On the whole, this pest is decreasing.

ST. KITTS. Widely distributed in certain districts, but not found on plants of any economic value.

NEVIS. Increasing year by year on hedges and cultivated plants.

BRITISH VIRGIN ISLANDS. *Cuscuta americana* is plentiful. It is a pest on many different plants, attacking such crops as cotton, pigeon peas, and cassava.

MISTLETOE.

ST. LUCIA. Fairly common on lime and cacao trees, but is receiving attention generally.

DOMINICA. *Dendropemon caribaeus*, the species which attacks lime trees, is abundant on some estates and is responsible for much damage. It should not be allowed to become prevalent on estates. Once this occurs, much time and money has to be expended before it can be got under control.

BRITISH VIRGIN ISLANDS. Common on certain fruit trees, especially avocado.

REMARKS ON ANY OTHER PLANT DISEASES.

ST. LUCIA. Rosel'inia root disease was locally prevalent on avocado.

ST. KITTS. What is known as o'd man's beard infests growing trees, and is very widely distributed.

SUMMARY OF DISTRIBUTION.

The following table is intended to show the status and distribution of the insects, fungi, and vegetable parasites attacking the principal crops. It has been drawn up from the information available at the Head Office of the Department, and has not been re-submitted to the officers in the various islands. While not claiming to be exact, it may be taken as affording a fair summary of the position during the year in question.

EXPLANATION OF SIGNS USED.

g = generally distributed.
G = generally distributed, severe.
l = local.
L = locally severe.
gL = Generally distributed, locally severe.
r = recorded present.
? = doubtful occurrence.
o = no record during the year

A blank against the pests or diseases of any particular crop means that the crop is not grown at all, or is not important in the island.

INSECT PESTS.

	Grenada.	St. Vincent.	St. Lucia.	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Bri. Vir. Islands.
Bananas and Plantains.									
Black Weevil Borer	r		G	gL		l	o		
Brown Weevil Borer	o		gg						
Black Hardback Borer			gg						
Cacao.									
Thrips	gL	gg	gL	r			l		
Beetle	L								
Acrobat Ant	gL	gg							
Scale Insects and Mealy-Bugs ...	gL		r	r					
Acrobat Ant	gL	gg							
Coco-nuts.									
Weevil	l	gg	r					o	?
White Fly	g	l	gg	r				o	?
Scale Insects	gL	gL	gL	r		gg		gg	l
Corn (Indian).									
Corn Ear Worm and Boll Worm	g	gL	gg			gg	G	l	L
Hardback Grubs						gg	o	o	
Cydosia histrio	r								
Grain Weevils			g						
Cotton.									
Cotton Worm	o	r			gL	G	G	G	G
Boll Worm and Corn Ear Worm					o	l	l	l	
Cotton Stainers	g	l	gg		gg	gg	gg	gg	l
Bush Bugs	r	gg	gg		gg	gg			r
Scale Insects	gg	l			l	l	r	g	o
Flower-bud Maggot						gg			
Leaf-blister Mite		g	L		G	gg	G	gg	gg
Aphis						l			
Green Dressings. (Beans and Peas.)									
Leaf-eating Caterpillars ...	r				l	gL	G		
Bush Bugs	o				gL	o			gg
Red Spider	L								
Grasshoppers							gg		

INSECT PESTS.—(*Concluded.*)

	Grenada.	St. Vincent.	St. Lucia.	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Bri. Vir. Islands.
GROUND NUTS.									
Green Bug	o	gL							
Mealy-Bug	o								
Leaf-eating Caterpillars ...	o	o	g						
LIMES AND OTHER CITRUS.									
Scale Insects	gL	G	g	g	G	g		G	g
Bark Borer	o		g	r				o	
Twig Borer						o		o	
Root Borers—Root Grubs ...	r		g			o		o	g
ONIONS.									
Caterpillars. Cut-worms ...	o					g	o	l	G
Thrips	O					g		g	
SUGAR-CANE.									
Moth Borer	g	g	g		gL	g	g	g	o
Weevil Borer	o	o	g			g	o	o	o
Root Borer (*Diaprepes*) ..	g		g			o	l	o	g
" " (*Exophthalmus*) ..	o						g	r	o
Termites—White Ants	o		r			l	O	O	
Hardback Grubs (*Lachnosterna*)						L	g		
Froghopper	r								
SWEET POTATOES.									
Scarabee—Jacobs	l	gL			gL	l	o	gL	?
Caterpillars	o	o	l		O	g	O	l	G
Thrips	G					o		o	?
Red Spider	g					r		o	?
TANNIAS, DASHEENS AND EDDOES.									
Banana Borer			gL						
Lace-wing Bug	o		g						
YAMS.									
Scale Insects	g		g		r	g	g	o	

PLANT DISEASES.

	Grenada.	St. Vincent.	St. Lucia.	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Bri. Vir. Islands.
Bananas and Plantains.									
Marasmius Rot	o		G						
Cacao.									
Root Diseases ... — ...	l		L						
Canker	gL		g	g					
Black Rot of Pods	L	g	G	g g					
Brown Rot of Pods	l		L	g g					
Die-back and Stem Disease ...	r		G	g					
Pink Disease	o								
Thread Blight	?		r						
Horse-Hair Blight	l								
Coco-nuts.									
Bud Rot	?					o	o	l	o
Red-ring Disease	L	o	?	o		?		o	o
Leaf Disease	l							o	o
Corn (Indian).									
Rusts	o		g			g	o	o	o
Smut	r					—	g g	g g	o
Root Disease	o						g g	o	o
Corn (Guinea Corn and Imphee).									
Rusts	r							g	
Smut	o							o	
Root Disease	o							o	
Cotton.									
Soft Rot of Bolls		gL			l		g	o	g
West Indian Leaf Mildew ..	r	g			g	g	g	g g	g
Bacterial Boll Disease	?	g L			r		g	G	g
Angular Leaf Spot	l	g L	l		o		g	G	g
Black Arm	l				o		g	o	g
Internal Boll Disease	l	L			gL	g	g	G	g g

PLANT DISEASES.—*(Concluded.)*

	Grenada.	St. Vincent.	St. Lucia.	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Bri. Vir. Islands.
Ground Nuts.									
Root Disease	o						o		
Leaf Rust	o	gL	gg		r		o		
Leaf Spot	o						o		
Limes and other Citrus Trees.									
Black Root Disease	o			L				o	
Red Root Disease								o	
Unidentified Root or Collar Diseases	L			r				o	
Die-back	l		r	r	gg				
Seedling Diseases	L			l	L				
Onions.									
Bacterial Rot	r				gg	r	o	o	r
Sugar-Cane.									
Root Disease	r	gg	gg			gg	gg	gg	gg
Rind Fungus	r	gg	gg			gg	o	l	gg
Red Root Disease		gg					o	o	gg
Pine-apple Disease			gg				gg	o	gg
Sweet Potatoes.									
Root Disease	o					gg		o	o
White Rust	o							o	o
Yams.									
Tuber Disease	o					o	o	o	
Wilt Disease	o					o	o	o	
Phanerogamic Parasites.									
Love Vine	ggL		gg	l	gg	l	gg	L	L
Mistletoe	gg		gg	L			o	o	l

NOTES ON TWO DISEASES OF THE COCO-NUT PALM IN JAMAICA CAUSED BY FUNGI OF THE GENUS PHYTOPHTHORA.

BY S. F. ASHBY, B.Sc.,

Microbiologist, Department of Agriculture, Jamaica.

I. BUD ROT CAUSED BY *PHYTOPHTHORA PALMIVORA*, BUTLER.

SYMPTOMS.

Macroscopic. - The existence of the disease is indicated by the pale colour, bending over, browning and breaking down of the heart leaf. Sometimes two or more of the youngest leaves lose colour and droop before the heart-leaf breaks down. More rarely one or more of the youngest leaves show rows of rounded spots running across the pinnae, before signs of drooping appear. Often enough the brown broken heart leaf is the first symptom noticed in an otherwise very healthy-looking crown. The withered heart-leaf can usually be drawn right out by a steady pull, as it is already rotted through at the base. This test serves as a rough practical means of distinguishing the disease from the common Leafbite due to the pine-apple fungus (*Thielaviopsis paradoxa*), in which the end of the heart-leaf frequently withers up but cannot be drawn out.

If the tree is allowed to stand after the heart-leaf dies, the young leaves next in order turn yellow, and the central column falls out, leaving a ring of the fully expanded leaves standing, and retaining colour frequently for many months; young nuts cease to develop and eventually fall, but those well-grown may mature.

If a tree with a dead heart-leaf is felled, and the dozen youngest leaves round the heart are cut off at the base successively, one at least will eventually be found to show a brown, firm sunken spot on the base, either at the thickest part or near the edge, or even in the strainer.

The spot pierces the limb, and can be followed through the underlying bases into the primordial tissue at the apex of the stem. The spots, yellowish when young and becoming light to dark brown or black later, can be found up to 3 inches in diameter on the thick bases, or even more in the strainer. Where the internal tissue is old enough to be fibrous it is brown and sodden, but firm, i.e. not disintegrated.

The primordial leaves and the non-fibrous apex of the stem are usually found partially or completely soft-rotted by the time the heart-leaf dies. If the disease is detected earlier, a succession of spots reaches into the primordial tissue, which becomes wilted and flexible, but firm with a soft rot starting at the edges. In the great majority of cases, however, the non-fibrous apex of the stem is already a semi liquid or pasty mass with a more or less offensive odour when examined.

Sodden patches are frequently present in the fibrous tissue just below the tender apex. The inner and outer faces of the spots on the leaf-bases may show a white mildew amounting

sometimes to a dense felt. This felt or web is often strongly developed between the rows of spots on the white adpressed pinnae of young leaves in the heart before they have been pushed up into the light. When such a leaf comes up, turns green, and opens out, dry webs which separate readily may be found on the inner faces of the rows of spots. As already pointed out, death of the heart-leaf is not in most cases preceded or accompanied by the appearance of rows of spots in young foliage.

The pinnae often break down at the spots, owing to failure of the ribs at those points; if a succession of leaves is affected, some with two or more rows of spots, the breaking down has the appearance of a severe Leaf Bitten Disease (Leafbite) resembling that caused by the pine apple fungus (*Thielaviopsis paradoxa*).

Microscopic.—The tissues of the leaf-base spots, of leaf primordia, and of stem apices where these are not already soft-rotted, are penetrated by a stout, sparingly septate, intercellular mycelium sending finger-like haustoria into the cells. In old spots the hyphae are often much thickened and have been observed to go across the cells showing constrictions where they pierce the walls. Pale-brown chlamydospores in the tissues are not uncommon.

The felts and webs on the leaf-bases and pinnae may show only sterile mycelium, often massed into stromalike bodies, or may be abundantly covered with pale-brown thick-walled chlamydospores, usually terminal, and often on short swollen stalks, but also intercalary; many of these will germinate in water within twenty-four hours from one or several points. If such a felt or web is kept for a day in a moist chamber, sporangia usually develop in abundance. They are oval, with broad prominent papillae, and where free are usually stalked; the apex of the stalk projects clearly into the body of the sporangium. The thirty or more zoospores are differentiated within the sporangium, and scatter as they discharge, or are gathered for a moment into a bladder before scattering.

Pure Culture.

Cultures have been made by plating out fragments from the internal tissues of spots on leaf-bases, diffused sodden rot of the youngest leaf stalks, and spots on pinnae. The medium used was an acid tartaric-saccharose-asparagin agar. Isolation from leaf-base spots required patience, as the fungus though obvious microscopically in the tissue, frequently failed to grow, or was contaminated by gas-forming bacteria and a small yeast. By increasing the tartaric acid in the medium to ·05 – ·07 per cent., bacterial growth was much restricted; the yeast is less injurious, so that pure cultures of the fungus were obtained from the edge of colonies which had spread well beyond the yeast growth. In some cases fragments of webs from spots on pinnae gave rise at once to pure colonies in the acid agar.

Lima-bean juice agar (100 – 15 – 1,000) was used as the standard medium for maintaining cultures. On slants of this agar the fungus spreads rapidly in the medium for the first couple of days before showing a moderate aerial growth. Sporangia are soon developed and characteristically in very great

abundance. Small white hyphal aggregates becoming yellowish are formed at the edges of the slant and on the glass, varying in amount with the strain. In old cultures thick-walled yellowish-brown chlamydospores are conspicuous, but oospores have never been seen in cultures of any strain. In old cultures many sporangia are empty although the mouth is still plugged. In culture the sporangia are borne simply at the ends of hyphae, and often also in a rather elaborate open branching system. The branches arise from swellings at intervals on young hyphae which eventually terminate in sporangia; these branches (most frequently either one branch or an opposed pair) grow out from the nodes and may again branch in the same way. They terminate either in a single sporangium or a cluster of three to five. The sporangia in such clusters are always terminal, a short branch growing out from below the base in a manner typical of Phytophthora. Each sporangium in the cluster has accordingly a short often stout stalk which remains attached when the sporangium becomes free.

In water cultures the open branching is lacking or reduced, and the sporangia are single or clustered at the ends of stout or slender hyphae.

A strain of the same species on one estate was found rotting the husks, and causing the dropping of full-grown but immature nuts.

The affected zone was dark brown with water-soaked margin, and spread from the stalk end, infection appearing to start under the scales.

Chlamydospores were found in the husk, especially in the larger spaces, and the mycelium was gathered into a stroma below the epidermis, which was raised and ruptured. Sporangia were borne copiously, either simply or in clusters, at the ends of short stout branches projecting from the exposed stroma.

Inoculations.

An attempt to infect a leaf-base on a ten-year-old bearing tree was successful. The older leaves were removed until a dozen were left. A fragment of agar culture was applied in a drop of water to the thickest part of an unwounded leaf-base and covered by a 3 × 1 cm. glass ring, with a vaselined lower edge, and a cover consisting of a disc of aluminium sheet attached with paraffin. The ring was secured with twine, and the whole leaf base covered with layers of strainer, and watered at intervals. Although the ring slipped off after a few days, an infection spot was present. At the end of six weeks a spot 2 inches across and 1 inch deep was found. At the end of another month it was scarcely larger and deeper, and was cracked and drying out. It was cut out, and microscopic examination showed abundance of typical intercellular mycelium with haustoria behind the advance margin of the rotted zone.

During the experiment there was much bright weather although the district has a rainfall of 90 inches. Penetration would probably have reached the underlying leaf-base had there been a continuous spell of wet weather.

An attempt was also made to cause infection by pouring suspensions of agar cultures into the hearts of actively growing trees four to five years old. In every case one or two of the heart-leaves pushing up later showed rows of typical spots on the pinnae, but succeeding leaves were free from spots, and the trees were still healthy a year later. This experiment confirms the observation that trees showing rows of typical leaf spots do not necessarily die at the heart, and may recover from the leafbite. To eight fully grown but immature nuts young agar cultures of the strain isolated from the husks were applied on the unwounded surface, both at the base, after removing some of the scales, and between the base and apex, and kept in air not fully saturated with moisture. Four of these nuts took the infection at the base and one in the middle In another experiment the surface was wounded beneath the inoculum, and in every case infection occurred at any part of the nut. The rot was allowed to spread throughout the husks, but in no case were the eyes penetrated, so that the meat and milk remained sound.

At one nursery in a district where bud-rot was very prevalent, seedlings were found with dead hearts and the apices of the stem rotted by Phytophthora, due probably to infection from the husks.

Measurement and Identity of the Species.

The hyphae in the tissues, webs and cultures vary in diameter from 4·5 to 8·5 micr. The haustoria are fingerlike and unbranched, with or without a cap. The sporangia vary greatly in size and in length.

In slant cultures on Lima-bean agar which have reached their full growth (two to three weeks), the mean ratio for all strains is about the same : between 152 and 157 with a variation of 33-36 micr. by 22-40 micr. and a mean of 45-50 micr. by 29-32 micr.

In young growing cultures (under a week) the length is relatively greater with a ratio of 175 177 and a mean of 54-57 micr. by 30-32 micr.

The sporangia in the web on a leaf-base spot had a ratio of 155, a variation of 33-62 micr. by 22-10 micr. and a mean of 45 micr. by 29 micr. On the husk of a nut the ratio was 162 with a variation of 36-72 micr. by 23 39 micr. and a mean of 47 micr. by 29 micr. The width of the papilla is usually two to three times the height (1-6 micr. by 2-2.5) micr. The zoospores are of the usual Phytophthora type, about 10 micr. by 8 micr. when active.

The chlamydospores in Lima-bean agar vary from 30-41 micr. with a mean of about 37 micr. In the webs on leaf-bases and pinnae, and in the tissues they are round or oval with a variation of 19-52 micr and a mean of 29-33 micr. The yellowish brown or brown wall may be up to 5 micr. thick. In nature the chlamydospores are usually terminal, often on short swollen branches, but in cultures they may be intercalary also. Intercalary sporangia are also not infrequent in cultures.

Oospores have not been seen in cultures although frequently looked for on bean and oat agar media during four years.

On one occasion oospores were found in the softened tissue just below the surface of an old leaf-base spot. They were of the type with persistent basal antheridium penetrated by the oogonial stalk.

Measurements of twenty-one of these oospores yielded a variation of 24-29 micr. with a mean of 26 micr., the thickened yellow oogonial wall varying from 30-36 micr. with a mean of 32 micr. As the fungus could not be isolated from this old spot, it is not quite certain that the oospores belonged to the present species, although they were too large for the second form described in this paper.

The symptoms of the disease, and the appearance of the fungus in the tissues and in the felts and webs on the spots of leaf-bases and pinnae corresponded so closely with Butler's description of a bud rot disease of palmyras and coco-nuts in India ([1, 2, 3]) that cultures of two strains were sent to Dr. Butler for identification. One of these cultures was alive on arrival, and after examining a sub culture he concluded that the species was identical with his *Phytophthora palmivora* (private communication), the name recent y adopted by him ([4]) for the species which he described originally as *Pythium palmivorum*. He has recorded ([3]) six successful inoculations with the fungus on unwounded leaf-sheaths of palmyra, and one on the leaf-base of a coco nut tree 8 feet high. Pure cultures were not used, but Shaw ([5]) working with pure cultures, obtained rows of spots on pinnae, collapse of the central leaves, and rot in the heart of coco-nut seedlings.

Distribution.

The disease is mainly restricted to the eastern and north-eastern coastal lands with large unbroken areas in coco-nuts, and a rainfall of about 90 to 120 inches. In these districts, trees ranging from two to three up to twenty years are liable to attack. Disease is to a marked degree most prevalent on the flat lands, especially on fine silt soils. There is evidence that the disease has been endemic in the eastern districts for many years, most estates losing a few trees each year. During the dry period 1906-12, losses were at a minimum. After 1912 disease increased throughout the whole area and was becoming especially marked in the most easterly section. Hurricanes in November 1915 and August 1916 damaged the tops of bearing trees, and a storm in September 1917 destroyed three-fourths of them in that district. A period of heavy rains is always followed by an increase of disease, dead hearts beginning to show up from one to two months later. In 1916 the rainy spell of October-November was followed by a great increase of disease, starting in December and continuing to March. Following the heavy rains of November-December 1917, many of the surviving trees died from disease in the period from February to April. This tendency was well illustrated by the records of one estate with 13,000 bearing trees from five to fifteen years old. During the period of eighteen months ending October 1916, 140 trees were cut down owing to bud rot, or an average of about eight monthly. After the heavy

rains and floods of October and November, the monthly numbers were the following: –

1916	...	November	35
"	...	December	115
1917	...	January	222
"	...	February	113
"	...	March	92
"	...	April	53
"	...	May	14
"	...	June	26
"	...	July	12

On a neighbouring estate during the period November 1916 to April 1917, a single field of 4,000 young trees about three years old suffered loss at the rate of over 100 per month. This was a mixed section in bananas and coco-nuts, the latter being spaced 42 by 28 feet. The soil was a fine silt difficult to drain, owing to its low situation, and also subject to flooding.

Young coco-nuts of the same age, in fields at a higher and better drained part of the cultivation, remained either free from disease or showed only a few cases.

Infection and Spread.

It has been pointed out that the infection which ultimately proves fatal to the trees starts in spots on the younger leaf-bases, and the fungus must penetrate several before it reaches the tender tissue of the bud. Spots have been observed to penetrate as many as five successive bases before reaching the bud, passing through the strainer and the thicker tissue in a direct course. As a rule only one spot can be detected on the outermost of the infected leaf-bases, indicating that disease had started from a single infection. Cases have been seen where the penetration reached the central leaf 6 inches or more above the tender bud, which nevertheless became rotted. In most of the cases examined leaf-base infection had not been preceded by attack on the pinnae of leaves still folded in the heart, and there was no indication that rows of spots had been present on any of the expanded leaves. In only a few cases of trees killed by bud rot has spotting of the pinnae been observed. The infection of leaf-bases by spores washed down from spots on the foliage of heart leaves is therefore not the rule in Jamaica, although Shaw ([6]) believes it to be the usual course in Malabar.

The period elapsing between the first infection and the withering of the heart-leaf depends on a number of factors, especially rainfall or humidity, and the number and thickness of the successive leaf-bases to be penetrated. Butler's observations on the penetration of palmyra leaf-sheaths can hardly apply to the coco-nut.

In 1916-17 following the August hurricane and the abnormal rains of October and early November, disease showed up strongly from December to March, which were dry months.

If a number of infections occurred at once after the storm and many again in October, penetration into the bud required, on an average, about four to five months with minimum and maximum periods of two and seven months.

Following the very destructive hurricane of September 1917, abnormal rains occurred in November-December, and dead hearts became very numerous from February to April 1918. Here again the time relations were about the same.

Nothing definite can be stated as to the means by which infective matter is conveyed into the tops of trees. The webs of mycelium on the younger leaf-bases bearing chlamydospores and more rarely sporangia are so effectually covered by the enveloping limbs with their strainer, that breezes cannot normally reach them. Where there is spot infection on pinnae of the heart-leaf, and high humidity, webs develop and may doubtless be swept away by strong wind as the leaf grows up and opens out.

Scavenging insects, especially beetles, earwigs, and cockroaches, can readily carry away fragments of mycelium and spores from spots to which they have access.

During a hurricane the tops may be so opened out that infecting matter which is not accessible to breezes under normal conditions may be swept away, and this doubtless accounts in part for the great increase of disease after the storms of 1916 and 1917.

It is improbable that the infection is spread to any appreciable extent by human agency, as the nuts are cut from trees of moderate height by a hooked knife fixed on a pole, and even where the trees are climbed the picker does not need to get up into the 'house'. If diseased trees are allowed to stand until the hearts fall out, the opportunities for the spread of disease by wind, rain and insects are obviously much increased.

The odour of the fallen hearts due to secondary bacterial soft rot quickly attracts johncrows (*Cathartes aura*) so that where treatment is delayed or neglected, those birds may be an agency for spreading infection. One estate in the eastern district where the incidence of disease was heaviest became a favourite grathering ground for johncrows.

Chlamydospores, set free by the decay of infested husks and limbs, and swept up by air currents, are also a possible means of spreading disease, if still capable of germination.

Treatment.

The destruction of dead hearts by fire after cutting down the trees has been compulsory since 1911. Although the large planters recognized the importance of this measure as the only effective means of preventing the spread of this bud rot, the burning was often done in a perfunctory manner. Many cases on the smaller cultivations escaped treatment owing to insufficient inspectors. Starting in 1918, a vigorous campaign of destruction was prosecuted under adequate supervision throughout the eastern districts. It is reasonable to conclude that the low incidence of disease now (December 1919) is due mainly to this systematic work.

A prophylactic treatment of non-diseased trees was carried on during 1916 17 at several large estates where disease was severe It was hoped that the application of fungicides to the hearts might ward off infection. The mixtures employed were

a dry powder of equal parts slaked lime and crushed sulphate of copper, Bordeaux paste (1 lb. sulphate of copper dissolved in 1 gallon of water to which is added 1 lb. of lime slaked in ½ gallon of water), Bordeaux mixture (5-5-50), a mixture of equal parts lime and salt, and rock salt alone. The copper mixtures were most favoured. The work was done by the planters at their own expense, and in their own way. The treatment was in most cases limited to two applications with an interval of several months, and the importance of leaving an untreated block of trees in each section for comparison was not properly realized. An extensive trial under more correct experimental conditions was brought to an untimely end by the hurricane of 1917, which destroyed most of the bearing trees. The results were inconclusive on the whole, although a marked reduction in new cases was observed in some fields.

Other Types of Bud Rot.

A form of bud rot differing in many respects from the type described has been prevalent in the western parishes for thirty years. It is rare in the eastern districts, while the form due to Phytophthora has not been detected hitherto in the West End. In both types the final condition is a soft stinking bacterial rot of the bud. The earliest symptom in the West End bud rot is usually the dropping of young nuts from one or more spikes, which blacken and wither up. The fully expanded leaves turn yellow, and the outermost give way at the base and hang down. These symptoms are followed after a variable interval, or accompanied, by withering of the youngest leaves in the heart, which finally falls over or out, leaving frequently a few leaves still upstanding. The latter soon collapse; and a bare pole results.

Examination of trees in different stages of disease reveals a diffuse brown sodden rot at the junction of the limbs, spikes and swords with the stem and isolated spots on the lower parts of those organs. Bacteria have alone been seen in the affected tissues, and in cultures made from them. Johnston ([7]) investigated this form of bud rot in the West End and considered it identical with the disease in Cuba. The same disease was described by Horne ([8]) in Cuba, and by Stockdale ([9]) and Rorer ([10]) in Trinidad. Johnston, Stockdale, and Rorer believed that the disease was due primarily to bacteria, and the same view was adopted by the writer ([11]). Johnston succeeded in producing a soft rot of the bud with cultures of the 'coli' group isolated from affected tissues. This was accomplished by means of an auger driven into the heart. No attempt was made to infect unwounded tissue. Reinking ([12]) has recently described a bud rot in the Philippines with the same external symptoms as that caused by Phytophthora. The disease starts in spots on the folded leaves in the heart, and extends down the central stalks into the bud, which becomes soft-rotted. Bacteria were alone found in the young affected tissues, and one species, apparently of the 'coli' group, was able to cause a similar rot when inoculated into growing points of seedlings wounded by scalpels. This is apparently the same type of bud rot that Copeland ([13]) had observed in the Philippines. Petch ([14]) had earlier attributed to bacteria a disease with similar symptoms attacking only young trees in Ceylon. All the successful pure culture inoculations

with bacteria recorded hitherto appear to have been made into wounded, and for the most part, extensively wounded tissues. There is difficulty in accepting this evidence as absolute proof of primary bacterial infection, although it shows that ubiquitous saprophytes of the 'coli' group may behave as wound parasites like the closely allied *Bacillus Carotovorus*, Jones, the cause of a soft rot in many kinds of vegetables. In the disease caused by Phytophthora, bacteria of the same group can usually be isolated from the spots on leaf-bases, and they doubtless are responsible for the soft rot of the bud by invasion of and growth beyond the tissue killed by the fungus, which has been proved able to penetrate unwounded surfaces.

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NOTE. Since completing this manuscript a second paper has been received from Otto. A. Reinking, entitled '*Phytophthora Faberi*, Maubl., the cause of Coco-nut Budrot in the Philippines' (*Philip, Jour. Sc.*, Vol. XIV, No. 1, 1919).

In this article bacteria are relegated to a secondary rôle, the primary infection being attributed to a Phytophthora—an interesting confirmation of the observations of Butler and Shaw in India and of the author in Jamaica on the similar type of bud rot.

Reinking, however, makes no references to lateral penetration into the tender bud through the leaf-bases, but describes a vertical downward penetration along the central leaf-stalks. He makes no mention of haustoria in the affected tissues, nor of felts and webs on the heart-leaves. He was able to produce

a similar rot in coco-nut seedlings through wounds, and in two cases out of ten without wounding, by means of the phytophthora from cacao pods, and obtained a slight rot of wounded cacao pods with the form from the coco-nut.

Identity was apparently not determined by detailed comparison of parallel cultures.

II. LEAF-STALK ROT CAUSED BY *P. PARASITICA*, DASTUR.

Symptoms.

Macroscopic.—The earliest symptom is usually a yellowing and withering of the tip of one of the leaves between the central region of the crown and the outermost limbs. One or more adjoining leaves then become similarly affected, and finally most of the outer limbs break down. The progress of the disease is slow, and hitherto only one case has been seen in which the heart-leaf and the bud were involved. This was a three-year old tree which had ceased to grow, owing to severe root injury due to percolation of paraffin oil from an adjoining pond. The bud was rotted, and the fungus was isolated from one of several small spots on a young leaf-stalk in the heart.

The bunches tear down and drop the large nuts, owing to loss of support from the affected limbs, but the disease has not been detected on the nuts and their stalks.

The stalks of the affected leaves show dark-brown somewhat sunken spots from one to several inches in diameter on the upper and under surfaces; the lowest spots are usually several inches above the union of petiole and stem. Long dark patches are also frequently present on the limbs, and gum may exude when the affected areas crack.

Internally the spots and patches show either a sodden rot with a narrow red margin, or are light to dark brown, depending on their age; frequently they pierce entirely through the limb.

Microscopic.—The tissue of young spots is penetrated by a stout sparingly septate intercellular mycelium, with few branches entering the cells. In older spots the hyphae show more frequent septation, and grow through the cells, so that it is doubtful if the short branches are true haustoria. Felts and webs have not been found on the surface of the spots.

Cultures.

Fragments of tissue plated out in acid saccharose-asparagin agar usually give rise to pure colonies of the fungus. On Lima-bean agar slants there is an abundant aerial white cottony growth which fills the space between the medium and the glass.

In contrast with the preceding species, sporangia are produced scantily on the agar, but develop abundantly when a fragment of the medium or the aerial growth is transferred to a moist chamber for one to two days. The sporangia are decidedly more globose in form with a narrower prominent papilla than in the preceding species, and are frequently intercalar in cultures. The tendency to break away with a stalk is also less marked.

In plates the growth tends to be tufted, and this is most marked in Sherbakoff's ([1]) corn meal agar.

Yellowish-brown mainly intercalar chlamydospores are present in old Lima-bean agar cultures, and with less certainty oospores as well. The latter have been found just below the dense surface mycelium in any part of the slant but most abundantly at the base. The oospore shows a thick hyaline wall and almost fills the oogonial cavity. The yellow oogonial wall surrounding the mature oospore is more or less thickened; the amount of thickening and colouration (the inner layer of the wall being hyaline) in the same medium depends on the maturity of the spore and the age of the culture.

The basal and persistent antheridium is penetrated by the stalk of the oogonium.

Measurement and Identity.

The aerial hyphae in cultures vary in diameter from 5-9·5 micr. and in the tissues from 6-8·5 micr. but may enlarge in places to 12 micr.

Tuberculate enlargements of the mycelium are frequent in corn meal agar and bean agar cultures. As sporangia in the strains isolated from the coco-nut are produced scantily on agar, measurements were made on those developed abundantly from fragments of culture lying in a moist cell for forty-eight hours. The length varied from 23-58 micr., and the breadth from 19-42 micr. with a mean of 37-40 micr. by 28-30 micr., and a ratio of 132-140.

The chlamydospores in cultures varied from 25-57 micr. with a mean of 36-39 micr.

The oospores and oogonial wall on Lima-bean agar from three strains have yielded the following measurements :—

	Oospores.		Oogonial wall.	
	Variation.	Mean.	Variation.	Mean.
	microns	*microns*	*microns*	*microns*
Strain 1 ...	14·6-22	18·6	19·5-25·6	23·3
Strain 2 culture a ..	14-20	17·3	18·5-26	22·0
„ b ...	15-20·5	18·4	24-26	24·6
Strain 3 ...	15-21·5	19·4	22-30	26·4

In culture (a) of the second strain the oospores were developed in dense masses within a week, which no doubt accounts for their size being smaller than in culture (b) where they were scattered. Strain 3 produced no oospores in several successive sub-cultures, but finally a few with the oogonial wall strongly coloured and much thickened. In the mature spore the hyaline basal antheridium varied in breadth from 11-13 micr., and in height from 8·5-11 micr.

Strains of apparently the same species have been isolated from stems of tobacco, and the leaf-bases and stems of pine-apple

(Ripley variety). Comparison with a culture of Sherbakoff's [1] *Phytophthora terrestria* from tomato fruits, showed the closest agreement, and the same is true in regard to Dastur's [2,3] description of his species *Ph. parasitica* from *Ricinus communis* and *Vinca rosea*. The dimensions of the oospores given below were observed by the writer on Lima-bean agar cultures isolated by him from tobacco and pine-apple, and in sub-cultures of a strain received from Sherbakoff. The measurements of the two strains of *Ph. parasitica* are those given by Dastur.

	Oospores.		Oogonial wall.	
	Variation.	Mean.	Variation.	Mean.
	microns	*microns*	*microns*	*microns*
Ph. parasitica (from castor)	15·20	18·6	18-25	23·8
do (from *Vinca rosea*)	15·23	18·4	(on oat agar)	–
Ph. terrestria	14·5-20·5	18·5	21-28	24·2
Tobacco	14·5-20·5	18·5	21-26·5	24·5
Pine-apple	14.5-20·5	17·0	21-26	23·5

The ratios for the sporangia in all the above strains agree with those from the coco-nut in lying between 130 and 140. Sporangia have been scanty in bean agar cultures from the coco. nut and pine-apple, but rather abundant in the other culture, including a strain from castor received from Dastur. Dastur (private communication) found oospores in a culture of one of the strains from the coco-nut received from the author, and considered them identical with those of his species. His examination of Sherbakoff's *Ph. terrestria* showed it to be identical with his species. He gives 35·8 micr. and 27·1 micr. for the mean length and width of the sporangia of *Ph. parasitica*, and a ratio af 137. The ratio of 182 given by Rosenbaum [5] for this species is for some unexplained reason widely divergent; the only known Phytophthora to which it could apply is *Ph. colocosiae*, Rac., exhaustively studied by Butler and Ku'karni [6]. If the size of the oospore, taken in conjunction with the structure of the whole apparatus, is the essential species character, then all are strains of one species, which on grounds of priority is *Phytophthora parasitica*, Dast. Petch [1] has described a disease in Ceylon with similar symptoms in the leaves, but also attacking the stalks and husks of the nuts; he found an undescribed phytophthora to be the primary agent.

Treatment.

The disease in Jamaica has been observed only on three neighbouring estates in a coastal district of high rainfall. Cases have occurred in trees from ten to fifteen years of age, but in greatest number on trees of five years beginning to bear.

Attempts to stay the passage of the fungus from limb to limb by cutting out the affected leaves and spraying the exposed bases with Bordeaux mixture, or smearing with Bordeaux paste, have not been succesful. More promising results have been obtained by packing banana or coco-nut trash round the affected limbs,and firing it.

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THE RED RING DISEASE OF COCO-NUT PALMS.

INFECTION EXPERIMENTS.

BY WILLIAM NOWELL, D. I. C.,

Mycologist on the Staff of the Imperial Department of Agriculture for the West Indies.

At the end of the writer's previous paper on this subject, published in *West Indian Bulletin*, XVII, No. 4, a note of later date was inserted giving a brief account of infection experiments. Fuller information regarding these is now supplied.

The experiments were made at the Government Coco-nut Plot at Westerhall, Grenada, on palms about seven years old. They were started partly by the writer, and partly by Mr. J. C. Moore, Superintendent of Agriculture, and were reported on by Mr. Moore and Mr. W. O'Brien Donovan, Agricultural Instructor.

I. STEM INOCULATIONS.

A row of six trees in good condition—Nos. 11-16 in the previously published plan—was selected in the higher part of the plot, where fewest natural infections had occurred. In the lower part of each stem (at 1-2 feet) a hole with a diameter of $\frac{3}{4}$-inch and a depth of about $2\frac{1}{2}$ inches was bored, with a bit which was sterilized each time of using. Into alternate trees a small fragment of fresh material from the red ring in an infested tree was introduced, and the holes in all the trees were closed immediately after they were made with plugs of tarred deal.

The inoculations were made in February 1919, and sixty days later the three inoculated trees, Nos. 11, 13 and 15, were cut

up and found to be fully infested with *Aphelenchus cocophilus*, Cobb, the nematode of red ring disease, while each had a pronounced red ring from base to bud, with the other usual internal and external symptoms in stem, leaves and heart.

The three alternate trees were at that time quite healthy in appearance. One of them, No. 16, died of the disease in November of the same year, nine months from the starting of the experiment. The other two remain healthy.

II. INOCULATIONS IN PETIOLES.

A half-inch cube of tissue was removed from the upper side of a petiole, a thin slice of infested material inserted, and the cube tied back in place. The inoculations were made on May 29, 1919.

TREE 64.

Inoculated in the petiole of an upper leaf (No. 17). Examined seventy-four days later.

Leaves.—At this time the inoculated leaf had yellow leaflets, brown at the extremities. The other leaves had a normal appearance.

The leaves were examined in order from below upwards, and the condition of the internal tissues of the petiole noted. Leaves 1-4 were normal. No. 5 had a slight discoloration at the base, Nos. 6 and 8 were recorded as 'suspicious', No. 7 was normal; from this point onwards to the soft leaves in the centre of the heart, all the leaves (Nos. 9–25) had strong positive indications of nematode infestation. The approximate linear extent of the discoloration in the bases of the leaves nearest the point of inoculation was as follows:—

Leaf	9	10	11	12	13	14	15	16	17 (inoc.)	18	19	20
Inches	9	9	9	12	18	18	18	18	rotted	30	24	20.

Some brown rot was present near the base of Leaves 15 and 19; the lower part of the petiole of Leaf 17 was fully rotted. This symptom is usually due to infestation with Diplodia following the injury caused by the worms.

The infestation was slight in Leaf 26, and absent from Leaves 27-30, in the centre of the heart.

Stem.—In a section 4 feet 6 inches from the ground there were only a few (6 1) visible red spots; at 6 feet there were scattered indications; at 10 feet (location of Leaf 20) the spots were distributed throughout the section.

There were no indications of infestation in the roots.

REMARKS.

Except for a plant about three years old infested in the leaves only, seen by the writer in Trinidad, this is the earliest stage of infection yet seen, natural infections not being detected until the colour of the leaves begins to fail. The notable points are the infestation of the petioles, centring about the point of inoculation, and the incipient nature of the infestation in the stem.

TREE 59.

Similarly inoculated, but in the petiole of a basal leaf. Escaped infection and is still healthy.

III. INFECTIONS IN THE AXILS.

Pieces of infested tissue, 2 or 3 inches long, were dropped into the axils of unwounded leaves.

TREE 36.

Pieces placed in all the leaf axils on May 29, 1919. Examined seventy-four days later. The nuts had been shed and were found lying on the ground. The leaves generally were either green to yellow or yellow to brown.

All the leaves, Nos. 1-34, had positive indications of infestation in the petioles. The mature leaves were heavily infested, the youngest leaves distinctly so.

The red ring was very pronounced from the base up to 8 feet, decreasing to disappearing point at the bud.

TREE 23.

One piece of infested material placed in the axil of an upper leaf (No 15) on May 29, 1919. Examined seventy-four days later. The six leaves nearest the point of infection were distinctly brown. The six next below these showed a less pronounced discoloration.

Leaves Nos. 1-7 were not visibly infested. No. 8 was infested for 10 inches, No. 9 was negative. Nos. 10-25, extending except for two rudimentary leaves to the centre of the bud, had positive indications of infestation. There was a marked dark discoloration under the situation of the infective material. Leaves 11-19, about the point of infection, were in an advanced stage of infestation, accompanied by putrefaction in Nos. 16-19. The stem and roots were unfortunately not reported on.

TREE 24.

One piece of infested material placed in the axil of a basal leaf, on May 29, 1919.

Appeared healthy seventy-four days later. Reported diseased November 1919, nearly five months from the starting of the experiment. Result regarded as negative.

GENERAL REMARKS.

Out of eight trees which it was attempted to infect, six were found infested after sixty to seventy four days. The two failures were trees in which infection was attempted on a basal leaf. During the period of the experiments, February August 1919, one case of failure from natural infection (Tree 57) occurred among the forty two remaining trees in the plot. The next case occurred in November of the same year.

The rapidity of infestation shown in these experiments obviously renders untenable the hypothesis put forward in the

writer's earlier paper that infection takes place at an early age without its effects becoming manifest until the tree matures.

The results support the idea that infection occurs in the leaf-bases, and more recent observations in Trinidad suggest that this may frequently take place by way of the small cracks which develop in the fold made on the outside of the leaf-base by the bending outwards of the leaf as it matures. In many leaves examined, there was a narrow streak of infected tissue connecting this point with well developed infestations in the softer tissue further along the petiole.

(Pages 1 to 76 issued June 21, 1920.)

THE GENESIS OF A FERTILE SOIL.

BY THE HONOURABLE J. B. HARRISON, C.M.G., M.A., F.G.S., F.I.C.,

Director of the Department of Science and Agriculture, British Guiana,

Assisted by

MR. C. B. W. ANDERSON,

Third Assistant Analyst, Department of Science and Agriculture, British Guiana.

Probably some, if not many, of the planters in the fertile island of Barbados have wondered how its soils, more especially the red soils of its higher levels, were produced. Schomburgk, on page 573 of his 'History of Barbados, (1847)', quoting Dr. John Davy, F.R.S. (brother of Sir Humphrey Davy) as his authority, wrote :—

> He observes, that the red soil of the higher grounds presents itself at heights where it could not be brought after the ground on which it rests, namely, coral and shell limestone, was raised from the depths of the sae, because there is no higher ground near from which it could have been conveyed by the action of water. Dr. Davy describes a hill, the summit of which consists entirely of red clay, near Horse Hill, and there is another near Sugar Hill. Barbados does not offer a singular instance of red soil resting on coral limestone, which some geologists suspect to be the residue of the limestone exposed for ages to the dissolving action of rain-water.

Dr. Davy (*loc. cit.*, p. 572) is also quoted as describing some of the soils which I propose to treat of as follows :—

> On the higher table-land, as near Mount Wilton, Lyon Castle, and Castle Grant, is a soil of reddish-brown hue, which, according to Dr. Davy, contains a large proportion of a siliceous matter in a very finely divided state, with a certain portion of clay, and an admixture in small quantities of lime and magnesia.

In describing the soils of Barbados on pages 50 to 56 of 'The Geology of Barbados,' written in collaboration with the late A. J. Jukes-Browne, F.R.S., F.G.S., I expressed my views as follows :—

In the coral area the most remarkable soil is certainly the red clay or loam which occurs on all the higher parts of the area. This is thickest on the very highest plateau above 900 feet ; below 800 feet it is much thinner, and it does not reach below 500 feet; indeed, between 500 and 700 feet it becomes rather a yellow clay, and is in many places covered and concealed by dark carbonaceous earth, the so-called 'black soil' which is black or brownish-black.

Where best developed, the red clay appears as an unctuous loamy clay of a deep red colour, or more often variegated red, yellow and brown, and it bears a great resemblance to the red and mottled clays which are so frequently found on the chalk districts of southern England. The average thickness of this soil on the high ground is from 2 to 3 feet, but the surface of the coral-rock is so very uneven that the depth of soil varies in every few yards—it fills up the hollows and is 'piped' into the holes by which this rock is honey-combed. Deep deposits of it are frequently found, and wells have been sunk 40, 50, and even in one case near Castle Grant 90 feet, without reaching the bottom of such clay-filled holes.

With regard to the origin of the red soil, we have no doubt that it has been produced by the gradual disintegration and solution of the coral-rock itself. At first sight it seems hardly possible that the decay of a nearly pure white limestone should result in the formation of a red clay, for the coral-rock is almost entirely composed of carbonate of lime, with generally less than 2 per cent. of silica and silicates, and only a minute quantity of oxide of iron; while the red soil contains about 60 per cent. of silica and silicates with 9 or 10 per cent. of iron oxide, and only some 2 per cent. of carbonate of lime.

It is, however, a fact that wherever a limestone is exposed to the slow solvent action of rain-water, a similar red soil is produced, and Barbadians need go no farther than San Domingo to find a case where this admits of proof, or along the western part of the south coast of that island, there are raised coral reefs covered by a similar red soil, and this soil is absolutely confined to the coral areas. Again in Jamaica a red soil occurs everywhere over the surface of the white limestone which forms such a large part of that island.

These red soils represent the residue of a great thickness of the limestone rock ; that is to say, they indicate the removal of a great thickness of the rock, the pure carbonate of lime having been dissolved by the rain-water which has fallen upon the surface and has then run off or percolated through to lower levels, while the small proportion of insoluble matter has been left on the surface or swept into its hollows. This mode of origin explains the fact of the red soil being thickest on the highest levels, for it is these parts which have been the longest above the level of the sea, and which have therefore been exposed for the longest time to the action of the rain and the weather.

Basing a calculation on the average amount of insoluble matter in the coral-rock, we find that from 50 to 60 cubic feet of such rock must have been destroyed in order to produce 1 cubic foot of the red clay ; and if we could ascertain the rate at which the destruction of the rock took place under natural conditions, we should have a basis for calculating how long it is since Barbados first rose above the waves.

Soon after the eruption of the St. Vincent Soufrière in 1902, the Consulting Chemist to the Barbados General Agricultural Society, Mr. George Hughes, F.C.S., suggested that Barbados derived its soil, if not altogether, at any rate in part, from falls of volcanic dust blown over similarly to those which fell on that island in that year during eruptions of the West Indian volcanoes. Mr. Hughes' exceptional knowledge of the soils of Barbados and his close acquaintance with volcanic soils in other of the West Indian islands should have caused his opinion to carry greater weight than apparently it did. He was well aware that the

final product of weathering of volcanic debris containing from 5·2 to 14·7 per cent. of ferric and ferrous oxides, from 12·5 to 22·6 of alumina with from 50·7 to 52·8 per cent. of silica, and from 9·4 to 10·1 per cent. of calcium oxide would be an earth or soil of a red colour or an ochreous tinge, of marly to clayey consistency, and containing a relatively low proportion of crystalline silica, much of which would be secondary in a fine state of division: in other words, an earth practically identical in colour and other physical properties with those he was so well acquainted with on the higher lands of Barbados. But little weight, however, was attached to his opinion, and the received position was described as follows on page 221 of Vol. I of the *Agricultural News* for 1902:—

The traces of old volcanic ash and sand appear to be confined to a very small portion of the island and are interstratified with oceanic deposits showing the existence of active volcanoes somewhere in the Caribbean region during the period of the accumulation of these deposits. The amount of volcanic ash that in recent times has fallen on the island and been added to form the present soil is scarcely worthy of consideration either from its bulk or its power of enriching the land. The amount of ash that fell in 1812 averaged only about three-eighths of an inch in depth, and the ash that fell this year was of about the same depth. The aggregate weight of ash that has fallen all over the island during recent times would appear considerable if stated in tons, but it would not form, probably, more than one per cent. of the total weight of the present soil of Barbados.

It was also summarized on page 285 of Vol. III for 1902 of the *West Indian Bulletin* as follows:—

It has been suggested that Barbados derives its soil entirely, or almost entirely from periodic falls of volcanic dust, blown over like that of 1812 and 1902 during periodic eruptions of the Soufrière, St. Vincent. There is however no evidence of this, and no reason to suppose it. The limestone rock of which the island is chiefly composed contains a proportion of material insoluble in dilute acids, and it is this material which forms the soil of Barbados. It is true that a large amount of limestone must have been dissolved away by water containing carbonic acid in solution before a thick layer of soil could be formed, but the soil of Barbados is by no means deep.

Professor Harrison computes from an analysis of the coral rock that 50 to 60 cubic feet must have been required to produce one cubic foot of soil.

Whilst writing the 'Geology of Barbados' from which extracts have been quoted, we, its authors, felt some diffidence in assuming that the red earths of Barbados were formed solely from the small amounts of mineral constituents which would have been contributed by the debris of corals, calcareous algae, foraminifera, mollusca, annelids, alcyonarians, echinoderms, and sponges, which with the remains of other organisms of less importance are the principal constituents of the Barbados coralline limestones. We discussed alternative sources, for instance, the possible drift of pumiceous material to the shores of the rising coral island, and its weathering *in situ* giving rise to the red earth; as well as the possibility that the red and mottled clays* of the Oceanic Series might have formed an exposed part of the rising island and thus supplied the mineral material for the red earth; but we did not feel justified in adopting either of them. With the view of enquiring into the probability of either of these, on my last visit with Mr. J. R. Bovell, I.S.O., to Little Island prior to my transfer to British Guiana in November 1889, I very carefully collected a sample of a deep-red coloured clay from a recently opened pot-hole on

*These contain numerous radiolarians and sponge-spicules which, as far as my experience goes, can only be satisfactorily separated from the clay by treating it in boiling 50 per cent. sulphuric acid.

the rock in a road cutting near to Castle Grant. Part of the sample was broken down for microscopical examination, but as I did not detect in the residue any radiolaria, the results of the examination were in accordance with Schomburgk's statement (page 573 of his History), that

the red soils from Sweet Bottom and from the road near Mount Wilton differ geologically in their age from those near the summit of Mount Hillaby; the former does not contain a single species of Polycystina, while the red soils from the northern declivity near the summit of Mount Hillaby, contain several. These fossil animals are entirely peculiar to the rocks of the Scotland formation, which is of great importance in the relative judgement of their ages, if compared with the coralline formation.

Hence the examination of the pot-hole clay was not carried further. As at that time there was some chance that I might be able to resume in Barbados, although in the possibly distant future, my studies of the coral limestone, the pot-hole clay sample was carefully preserved. Its later laboratory studies will form a part of the present paper.

In discussing with Jukes-Browne the origin of the red soils, I showed a strange absence of scientific prescience, as we regarded the absence of defined beds of volcanic debris, such as are of very frequent occurrence in the Oceanic Series—(for instance, Conset's Gulley section supplies evidence of over fifty volcanic outbursts each of which must have far exceeded in intensity any of the historically recorded ones)—to be an indication that volcanic activity in the vicinity of the rising coral-limestone island was reduced to a minimum during the long period which elapsed from the end of the Pliocene to—geologically-speaking—comparatively recent times in which the limestones were built up.

No beds of volcanic debris had or have been found in the coral-limestone, nor is it probable that such beds exist. These limestones were formed, as are the coral reefs at present encircling much of the island, in shallow water with innumerable shifting currents caused by the prevailing winds, the rise and fall of the tides, and the waves, and especially the breakers of the Caribbean Sea and Atlantic Ocean.

Any fall of volcanic ash therefore would not accumulate as a definite bed in the limestone, but its materials would be disseminated over the growing corals, the lagoon and channel deposits, and the beach-limestones in course of formation, whilst by far the greater part probably would be washed away into the deeper waters. On the land-surface of the rising island the position would be different, any falls of volcanic ash accumulated, gradually becoming incorporated with the slowly forming earthy mantle of the island. In places the ash, especially where wind-blown in gulleys and sheltered hollows, might temporarily form more or less well defined beds or deposits, as in a few places there were of the 1812 ash when I commenced residence in Barbados over forty years ago.

Among the weightier of the criticisms directed against Mr. George Hughes' suggestion was one that the amount of material contributed by any one volcanic outbreak would be practically negligible when compared with the mass of the soil which covers the island. This criticism was based on the fallacy that showers of volcanic ash in bygone times would not have been greater than those of 1812, 1902 and 1903—showers which fell in the present period of gradual extinction of volcanic activity in the

West Indian Province. But the geological record shows that numerous falls of volcanic debris had occurred during the period of depression in which the Oceanic Series accumulated, resulting, as is well seen in Conset's Gulley, in many beds of volcanic ash from 2 or 3 inches to as much as 2½ feet in thickness; in a bed of pumiceous debris exposed near Chimborazo about 5 feet in thickness; whilst on Mount Hillaby the topmost 25 feet consist of compacted, volcanic debris or mud-stones. These facts might have given pause to Mr. Hughes' critics.

Probably the most enthusiastic collector of paleontological and geological specimens who ever resided in Barbados, was the late G. F. Franks, M.A., F.G.S. my companion in many geological rambles in Barbados during the eighties of the last century. His collection of fossil corals largely formed the basis on which Prof. J. W. Gregory, F.R.S., D.Sc., built his classical paper on the 'Paleontology and Physical Geology of the West Indies' (*Q. J. G. S.*, Aug. 1895). Franks at his death in July 1917, bequeathed to me his collections of Barbados rocks, and of microscopic slides prepared from them. Whilst examining some of the slides, specks of felspar with but rarely a speck of pyroxene were seen in the coral-limestone, and in connexion with the soil-work I have been carrying on for some time I considered it advisable to separate and examine any extraneous minerals which might occur in the limestone. Among the specimens Franks left me was a series of fragments of fossil corals, valueless from a paleontologist's point of view, but which were duplicates of those he sent to Gregory in 1892, and also many specimens of low-level beach rock. These materials were very carefully cleaned, and then gradually dissolved in very dilute, approximately deci-normal, hydrochloric acid in the cold. In earlier work with Barbados rocks in 1888 and 1889 I had found that very dilute cold hydrochloric or nitric acid has no greater solvent effect on the earthy or clayey constituents of limestone than has dilute acetic acid. From the corals I obtained 308 per cent., and from the beach-rock, 223 per cent. of extraneous insoluble matters. To obtain sufficient of these matters for analysis, I had to dissolve all the material I had—from 600 to 800 grams, of the corals and beach-rock, respectively. The results of the examination were of much interest, and I communicated them to Sir Francis Watts, K.C.M.G., with a request that if he considered them of importance he would obtain for me larger samples of corals and of beach-rock from the higher coralline limestones of Barbados. Through the kindness of Mr. F. W. Greaves, excellent samples of corals and of beach-rock were obtained for me from the following localities:—

Corals.			Beach-rock.		
Locality.		Elevation in feet.	Locality.		Elevation in feet.
Mt. Misery (calcitic coral)	...	about 1,055	Bloomsbury	...	about 1,035
Bloomsbury	...	„ 1,035	Mt. Wilton	...	„ 937
Blackmans	...	„ 900	Blackmans	...	„ 900
Dunscombe	...	„ 850			
Vaucluse ...	...	„ 731			

Mr. F. W. Greaves took great care in ensuring that the specimens were taken from where they could not have been contaminated by the 1812, 1902 or 1903 falls of volcanic ash; while I took the samples for examination of the corals and of the beach-rock from the interior of the specimens so as to make quite certain that no accidental contamination could have occurred in them. Quantities of 1,000 grams of each were dissolved in dilute hydrochloric acid, and the residues collected for examination.

The method used was to support the fragments of limestone in a shallow perforated porcelain filtering dish immersed just below the surface of several litres of the diluted acid, which as neutralized by solution of the calcium carbonate, received additions of hydrochloric acid in small quantities at a time so as to keep the liquid approximately at its original degree of acidity. As the limestone slowly dissolved its insoluble matters gradually subsided to the bottom of the diluted acid. After complete solution of the rock was effected, the liquid was allowed to stand until it had become quite clear through the sedimentation of the insoluble residue. The liquid was decanted off, and the sediment washed with distilled water by subsidence and decantation until the acid was almost entirely removed. The insoluble matter was then decanted into a large, porous, alundum filtering cone, and drained. The residue was washed in the cone with distilled water until all soluble matter was removed. It was next washed off the interior of the cone by a jet of distilled water into a tared platinum basin in which it was dried at 105° C., and weighed. The dried residua were then analysed, both chemically and microscopically, by well-known standard methods for such work.

The results of the preliminary work are shown in the following:—

Specimens.	Per cent. of specimens.			
	Extraneous matter.	Mineral residua.	Organic residua.	Nitrogen.
Mt. Misery coral (1) ...	·5993	·5870	·0123	·0008
Other high-level corals (2) ..	·0912	·0809	·0103	·0002
High-level beach-rock ...	·3338	·3232	·0106	·0009
Lower level corals (3) ...	·308	·214	·094	·0057
Lower level beach-rock ...	·223	·184	·039	·0024

(1) Eusmilia
(2) Diploria, Orbicella and Eusmilia
(3) Agaricia, Astrea, Colpophyllia, Dendrogyra, Dichocoenia, Eusmilia, Madracis, Madrepora, Maeandrina, Mussa, Mycetophyllia Orbicella, Pectinia, and Porites.

Dr. F. W. Clarke, Chief Chemist, and Dr. W. C. Wheeler of the United States Geological Survey, published in 1917 'Professional Paper, 102' giving the results of an exhaustive enquiry into 'The Inorganic Constituents of Marine Invertebrates.' They summarized, on page 12, the results of their work with massive corals as follows :—

These analyses are remarkably concordant, and show that the stony corals contain little besides calcium carbonate. Silica and sesquioxides are probably extraneous : magnesia is altogether subordinate, although fairly regular in its amount ; phosphates occur only in traces.

From the tables of 'Reduced Analyses' given by the authors on pages 13 and 14, the proportions of silica and sesquioxides found by them were :—

	Maximum.	Minimum.	Means.
Silica	·41	·00	·132
Alumina and iron peroxide ...	·74	·00	·134

The authors deal on page 1 with the minor inorganic constituents of marine invertebrates in the following words :—

In a strict sense completeness cannot be claimed even for our analyses. Minor constituents which have been detected in shells, corals, and seaweeds, such as lead, copper, and manganese, have been ignored. They occur only in traces and have little or no significance with respect to the larger problem before us.

The proportions of extraneous mineral matters I found in the fossil corals, other than the calcitic coral from Mount Misery, fall within the limits of total silica and sesquioxides found by Drs. Clarke and Wheeler. The proportions found in the Barbados upper and lower level beach-rocks, ·323 and ·184 per cent. respectively, fall within the limits which their investigations indicate should characterize a limestone of similar complex origin. If the extraneous mineral constituents of the Barbados limestones consist only of silica and sesquioxides in the average proportions found by Drs. Clarke and Wheeler, soils derived from them should be heavy clays. This is not the general character of the higher-level red soils of the island.

To ascertain the composition, nature and origin of the extraneous mineral or acid-insoluble constituents of the coral limestone, analyses, both chemical and microscopical, have been made of the residua obtained by the mode I have described, with the following results :—

Ultimate chemical compositions.

	1	2	3	4	5
Quartz		·06	2·12	13·06	20·11
Silica (organic)	2·07	1·65	1·49	6·54	4·07
Combined silica	41·08	35·58	44·44	36·36	32·82
Combined water ...	11·59	11·87	9·37	4·82	8·13
Alumina	27·47	27·32	22·03	16·68	21·38
Iron peroxide	13·26	14·49	12·64	10·95	6·15
Iron protoxide	·88	2·24	·79	2·59	2·27
Manganese oxide ...	nil.	·37	·84	nil.	nil.
Titanium oxide	1·75	2·58	2·00	1·98	1·52
Calcium oxide	·45	·21	·70	2·60	·20
Magnesium oxide ...	1·44	1·47	1·83	1·21	1·39
Potassium oxide ...	·27	·59	1·43	1·09	·92
Sodium oxide	·39	1·45	·35	2·70	·90
Phosphoric anhydride ...	·02	·01	·01	·02	·01
	100·67	99·89	100·04	100·60	99·87

1. Mount Misery coral.
2. High-level corals.
3. High-level beach-rock.
4. Low-level corals.
5. Low-level beach-rock.

The analyses were made so as to separate the constituents of the residue unattacked by hot sulphuric acid from those constituents which are thereby rendered soluble in dilute acids or, in the case of silica, in a warm dilute alkaline solution. The constituents of the acid-resistant fractions are shown in the following table:—

Percentage compositions of
the mineral constituents not decomposable by hot sulphuric acid.

	1	2	3	4	5
Quartz	nil	1·05	39·77	33·26	64·09
Combined silica	72·10	71·57	43·63	40·30	22·64
Alumina	6·60	11·13	8·68	11·05	6·68
Iron peroxide	nil	nil	nil	2·55	nil
Iron protoxide	5·07	7·56	4·63	1·63	1·46
Titanium oxide	nil	nil	·58	·18	·19
Calcium oxide	9·64	·84	·39	3·70	·64
Magnesium oxide ...	4·06	1·68	1·16	1·04	1·11
Potassium oxide ...	2·03	1·05	·78	1·35	·76
Sodium oxide	·51	2·10	·39	5·12	2·41
	100·01	99·98	100·01	100·18	99·98

Some if not all of the quartz in the residue from the rocks of the higher levels is secondary crystalline silica, whilst part, if not the whole, of that from the lower-level corals and beach-rock is clastic, and derived from the quartz sand beds of the Scotland Series exposed on the eastern section of the island. The analyses

therefore have been re-calculated to eliminate the quartz. The results are as follows : —

Percentage compositions of
the mineral constituents other than quartz.

	1	2	3	4	5
Combined silica	72·10	75·35	72·43	60·22	63·04
Alumina	6·60	11·25	14·42	16·51	18·60
Iron peroxide	nil	nil	nil	3·81	nil
Iron protoxide	5·07	7·64	7·69	2·43	4·06
Titanium oxide	nil	nil	·96	·27	·53
Calcium oxide	9·64	·85	·64	5·53	1·78
Magnesium oxide ...	4·06	1·70	1·92	1·55	3·09
Potassium oxide ...	2·03	1·06	1·28	2·03	2·11
Sodium oxide	·51	2·12	·64	7·65	6·71
	100·01	99·99	99·98	100·00	99·92

These analyses of the extraneous mineral constituents of the Barbados limestones indicate that in addition to ferruginous kaolin which may have been derived from extremely finely-divided clay held in suspension, or even in colloidal solution, in the sea or ocean waters, they consist of minerals of volcanic origin.

As I invariably do in analyses of this description, the chemical work was checked by microscopical examination of the material used and of the various parts separated. It was found that in every case the extraneous mineral constituents were hydrated aluminium silicate—kaolin or halloysite— with numerous flakes of orange and lemon-yellow limonite ; minute red fragments of hematite, and numerous fragments of volcanic minerals and glass.

Before making the detailed microscopic examination, the heavy minerals, including hornblende and pyroxene, were separated from the lighter ones by the use of a Sonstadt solution of Sp. Gr. 2·90. The fragments of the lighter minerals were approximately separated into basic plagioclase, quartz, sanidine, and glass by bromoform suitably diluted with 98 per cent. alcohol Owing to the minute size of the fragments and to many of them containing inclusions of other minerals or of gas-bubbles, it was not feasible to make these separations quantitative.

The following are descriptions of the microscopical examinations of the residua :—

The residue from the calcified coral of Mount Misery, in addition to kaolin and abundant flakes of limonite and grains of hematite, contains only a low proportion of crystalline and glassy minerals. With the exception of some very minute but perfect crystals of hypersthene, the minerals present are broken and sharply angular, the fragments of volcanic glass consisting of conchoidal, very sharply-edged flakes and splinters. Very few of the fragments of felspar consist of plagioclase, most of them being glassy sanidine. There are a few flakes of dark-brown biotite, and some angular

fragments of green and of colourless augite, and of a dark-green hornblende. A small crystal of zircon, and some minute crystalline fragments of titaniferous iron were also found. The main part of this residua is, however, kaolin and limonite. Quartz is entirely absent.

The massive corals of the higher reefs, Astreans probably of the species Eusmilia, Diploria, and Orbicella, yield only small proportions of extraneous mineral matters. Prominent among these are small globules of non-striated felspar containing innumerable crystallites and globulites or vacuoles; a few sharply angular minute fragments of green and of colourless augite, and of hypersthene; whilst sharply angular conchoidal flakes of both brown and colourless glass are present. Quartz is present in the residua in only very minute, practically negligible proportions. Ferruginous kaolin and limonite are present in lesser proportions in these residua than in that from Mount Misery, the former containing, in round figures, 66 per cent. of these earthy constituents as compared with 84 per cent in the latter.

Like the residua from the Mount Misery calcitised coral, those from the high-level beach-rock contain large proportions of kaolinic and limonitic materials—76 per cent.—but volcanic debris is more largely in evidence in them. Small angular fragments of quartz are present but not in any quantity. The largest fragments are blebs of felspar, some being non-striated, others, however, showing faintly the characteristic striae of albite, all containing innumerable globulites, vacuoles, and crystallites. Generally the larger fragments have a less sharply angular appearance than have those of the coral-rocks. The finer constituents are very numerous, and consist largely of colourless, brown and dark-green glass in small, very sharply angular conchoidal flakes and splinters, some of the larger pieces having a pumiceous structure containing numerous minute air-bubbles, whilst others show inclusions of magnetite. There are also angular and sub-angular to partly rounded fragments of green and of colourless augite, and of hypersthene; a few of green-brown hornblende; very abundant minute angular ones of sanidine, some with microlites and globulites, while some fragments of felspar faintly show the characteristics of plagioclase. Rarely a wisp of dark-brown biotite, and still more rarely a fragment of brown tourmaline is seen; while a fair number of fragments of magnetite, of ilmenite, of hematite and, but rarely, of pyrite are found.

The minerals found in the residua of the high-level limestones indicate either an origin from outbursts of acidic volcanic rocks, such as trachyte, containing comparatively low proportions of basic plagioclases and of ferromagnesian minerals, or ejectamenta from more basic rocks, such as andesite or basalt, in which case the two latter constituents have been decomposed by lateritisation and weathering to limonite and kaolin.

The extraneous matter from the low-level corals proved to be sub-angular grains of green augite—the characteristic West Indian pyroxene—some angular fragments of hypersthene; much plagioclase-felspar in sharply angular fragments, some very finely divided fragments of sanidine, a little glass in minute splinters, a few specks of ilmenite, and with much ferruginous kaolin

and quartz in the proportions of 32·8 and 13 per cent respectively. Some of the blebs of plagioclase contain minute crystals of the green augite. The larger grains of augite are characterized by the usual inclusions, some of these being very minute octohedra of magnetite; while some of the blebs of felspar and fragments of glass have inclusions of microlites, or of air-bubbles.

The extraneous matter of the low-level beach-rock contains a few minute prisms of green-brown hornblende, a very few minute grains of hypersthene, some flakes of chlorite; a little plagioclase, and many finely divided fragments of sanidine; a few minute grains of ilmenite; with kaolin and grains of quartz in greater relative quantities—52 and 20 per cent. respectively—than they are in the coral-residua.

The sizes of the largest grains of the minerals present in the samples examined are:—

	Millimetres.		
	Felspar.	Pyroxene.	Glass.
Mount Misery	·20 × ·10	·07 × ·07	·13 × ·12
Blackmans	·66 × ·50	·23 × ·12	·10 × ·10
Dunscombe	·75 × ·28	·30 × ·20	·30 × ·28
Vaucluse	·67 × ·47	·14 × ·08	·10 × ·10
High-level beach-rock ...	·65 × ·35	·18 × ·08	·25 × ·21
Low-level corals	·70 × ·62	·75 × ·38	·10 × ·10
Low-level beach-rock ...	·60 × ·25	·53 × ·30	·40 × ·20

The mean sizes of the larger fragments are as follows:—

	Felspar.	Pyroxene.	Glass.	Kaolin and limonite.
High-level reef-corals ...	·46 × ·38	·14 × ·08	·10 × ·10	·07 × ·04
High-level beach-rock ...	·34 × ·25	·13 × ·09	·20 × ·13	·06 × ·04
Low-level corals ...	·36 × ·25	·25 × ·16	·11 × ·07	·06 × ·04
Low level beach-rock ...	·21 × ·16	·30 × ·18	·27 × ·20	·05 × ·04

The majority by far of the fragments of minerals and splinters of volcanic glass in every residue examined are less than ·18 mm. ($\frac{1}{140}$-inch) in diameter; that is, they are similar in size to the fragments of volcanic debris which fell on Barbados in 1812, 1902 and 1903.

The analyses and the microscopical examinations of the residues, both as separated from the coralline limestone and from the beach-rock by very dilute acid and after treatment with hot sulphuric acid followed by a weak alkaline solution, prove that in every case the extraneous mineral constituents consist of hydrated aluminium silicate—kaolin or halloysite—usually deeply stained with limonite, flakes of orange-yellow limonite, minute fragments of red hematite; and many specks of volcanic minerals, such as felspars and pyroxenes, with splinters of both acidic and basic volcanic glass.

Not unfrequently the mineral fragments are enclosed in minute masses of kaolin, hematite, or limonite. The direct microscopical examination of the residua separated from the corals and beach-rocks by very dilute acid, shows that if the examinations were not specially directed towards the search for mineral fragments, the extraneous mineral-constituents would be regarded as consisting essentially of kaolin and limonite, with only negligible specks of felspar and, possibly, of quartz.

The proportions of the volcanic minerals, including the splinters of glass, can be approximately estimated from the quantities of the oxides of sodium, potassium, magnesium, calcium, iron (ferrous), and titanium, shown in the analyses of the residua. These indicate that the percentage compositions of the mineral residua are approximately in round figures, as follows:—

	1	2	3	4	5
Organic silica (sponge spicules)	2	2	2	6	4
Quartz			2	13	20
Kaolin	67	37	50	22	45
Limonite, hematite, etc.	17	29	20	12	8
Volcanic minerals and glass	14	32	26	47	23

1. Mount Misery coral.
2. High-level corals.
3. High-level beach rock.
4. Low-level corals.
5. Low-level beach-rock.

While I adduce evidence that the extraneous mineral matters in the Barbados limestones are largely, and possibly entirely, of volcanic origin, and that the resistant minerals in the residua have the characteristics of air-borne volcanic debris or ash, the possibility still remains that they may be of secondary deposition in the coral-limestone, and derived from some of the volcanic ash-beds of the Oceanic Series. The volcanic minerals in these beds, however, have not the ideally fresh appearance which characterizes those separated from the coral-limestone, but show the chemical effects due to their subsidence to and deposition on the bottom of the ocean.

Investigations made by the late G. F. Franks and myself after the publication of 'The Geology of Barbados' proved that during the period in which the basement formation of Barbados —the Oceanic and the Scotland Series—were undergoing the slow upheaval which eventually gave rise to the island, a somewhat thick series of marine deposits accumulated on the rising surface of these formations (*Q.J.G.S.*, J. W. Gregory, Vol. XLVII, 1902, pp. 163-69; Jukes-Browne and Harrison, Vol. XLVIII, 1902, pp. 212-16; Franks and Harrison, *Q.J.G.S.*, Vol. LIV, 1898, pp. 540-55.) At Bissex Hill and its vicinity, Franks and I found a thickness of about 90 feet of these beds (globigerina marl) covered by about 20 feet of foraminiferal reef-rocks; Franks was not able at Bowmanston to determine the thickness of the globigerina-marl which my notes show I first detected there on May 22, 1882, but he found that the marl was covered by some 50 feet of globigerina-limestone gradually passing through amphistegina into coral rock. Many of the borings put down by the late Edward Easton, C.E., F.G.S.,

proved that between the base of the older coral-limestones and the underlying Oceanic or Scotland rocks, the series exposed at Bissex Hill and in the old shaft, and in the cavern at Bowmanston occur. During later visits to Barbados I have found evidence that originally, the intermediate formations were far wider-spread than we knew them to be when the 1892 and 1898 papers were written, and that their debris is widely scattered in the alluvial valleys and flats of the Bath-Conset, and Scotland districts. Hence if the present highest terraces of coral limestone accumulated around a land-area since denuded away, that area probably consisted of the globigerina-marls and foraminiferal limestones which then covered and protected the higher parts of the Oceanic and of the Scotland Series, although in places the coral-limestone has been deposited directly on the denuded slopes of these strata. In view of this the sharply angular characters of the mineral fragments and glass-splinters of the residua from the high-level rocks deposited directly on the coralline-limestone lead me to regard them as derived from air-borne volcanic debris.

These observations and analyses, and deductions therefrom indicate that the extraneous mineral matters in the high-level limestones were derived from volcanic sources, and that their limonite, kaolin or halloysite, and secondary crystalline silica, where it occurs, are the normal decomposition or weathering products of lime-soda felspars, and of ferromagnesian minerals, both of which classes of minerals are present in relatively high proportions in the unaltered modern volcanic ash from the Soufrière of St. Vincent, and from Mont Pelè, Martinique. Both lime-soda felspar and ferromagnesian minerals are of comparatively rare occurrence in the residua of the high-level beach rock, and hence much of them which may have originally been present in the volcanic ash have been altered into limonite, kaolin, and secondary silica by detrital and weathering actions.

The extraneous minerals in the low-level limestones are more varied than are those in the high-level ones, and contain lime soda felspar, and pyroxene in considerable proportions; they also contain quartz in fair quantities, derived probably from the older Scotland beds, which at the time of their formation were higher than the low-level limestone, and hence were exposed to atmospheric degradation, and their constituents washed, as at present, into the surrounding sea during heavy rainfalls.

With reference to the soils on the lower levels, Schomburgk (p. 573 of his 'History of Barbados,' 1847) quoted Dr Davy as stating—

> the soils on the table-land and Sweet Bottom arose from the subsidence of drift-matter, brought by the currents when these parts were lying at a considerable depth in the ocean.

whilst much later, in 1890, I wrote ('Geology of Barbados,' p. 53):

> The black earth soil is only found on the lower parts of the coral-rock area from about 500 feet downward. It partakes more of the nature of an alluvial soil, and the fact of its overlying a reddish or yellowish clay in many places proves that much of its material has been brought from higher levels, and it is probable that the red clay is actually in process of formation beneath it, though this process must now be going on much more slowly than it did formerly when the natural vegetation *died and decayed* on the ground.

This paper does not affect either Dr. Davy's or my earlier views, but shows that, as pointed out by Mr. George Hughes, even the low-level soils must owe at any rate a large part of their constituents to volcanic sources.

If my deductions as to the origin of the extraneous mineral constituents of the high-level limestones are correct, evidence of the present or former existence of volcanic minerals should be obtainable from the naturally separated weathered residua of the limestone. With this object I examined, both chemically and microscopically, the sample of deep-red clay collected by J. R. Bovell and myself from a road-side pot-hole at Castle Grant in November 1889. The results of the chemical analysis are as follows :—

(1)	Organic matters	2·40
	Combined water	7·60
	Chalcedonic silica	7 30
	Organic silica (sponge spicules) ...	9·81
	Combined silica	31·65
	Alumina	23·98
	Iron peroxide	13·41
	Iron protoxide	·32
	Titanium oxide	2·33
	Manganese oxide	·02
	Calcium oxide	·08
	Magnesium oxide	·12
	Potassium oxide	·36
	Sodium oxide	·61
	Phosphoric anhydride	·015
		100·005
	(1) Containing nitrogen ...	·097

The high proportion of titanium oxide in the pot-hole clay ndicates the probable derivation of the clay from volcanic sources, such as a basalt or a pyroxene-andesite. My earlier examinations of the clay were not satisfactory as I did not break down the chalcedonic silica contained in it, and hence obtained very scanty indications of residual minerals. When I renewed my examinations, I found that the chalcedonic silica which was resistant to solution in warm alkaline solution of a strength equal to 2 per cent. of sodium hydrate, dissolved fairly readily in hot 20-per cent. solution of sodium hydrate, although this liquid only partially attacked and dissolved the more robust of the siliceous sponge spicules or megascleres present in the residua.

Microscopical examinations proved that the resistant minerals in the residua consist of numerous minute grains of sanidine, the larger with dulled, and more or less corroded surfaces, and partially rounded outlines as if from the effects of commencing weathering ; some of the felspar-fragments have inclusions of microlites or of vacuoles, whilst one angular fragment shows the structure of albite, and a few that of microline ; here and there, but rarely, minute fragments of hypersthene, of a blue-green hornblende and of tourmaline occur ; while a few small fragments and some splinters of brown and of green volcanic glass are present. The edges of the ferromagnesian minerals are worn

so that some fragments are sub-angular. The dulled surfaces and partially smoothed-off outlines of the minerals in the pot-hole clay are such as the minerals would show if they had been weathered out from the limestones by solution of its carbonates, and thence piped into the pot-hole; they therefore confirm my views as to the origin of the clay. In the residua separated without the use of acid and alkalies, many siliceous sponge spicules, and some kidney-shaped blebs of opaline silica are present. A very few minute blue specks of vivianite ($3FeO, P_2O_5, 8H_2O$) were detected in this residium. The other iron minerals found in it are hematite and limonite, neither magnetite nor ilmenite being present.

The analyses and the microscopical examinations indicate that the proximate composition of the clay of the pot-hole is, in round figures :—

Organic matters	2
Organic and amorphous silica (sponge-spicules, etc.)	10
Chalcedonic silica	7
Kaolin	57
Limonite, hematite, etc.	12
Volcanic minerals and glass	12
	100

These residua, both artificial and natural, show that separated from the limestone without either chemical or mechanical loss, they would give rise to fertile soils of favourable physical texture and chemical composition, which would contain the important constituents of plant-food in the following proportions :—

	1	2	3	4	5	6
Organic matters ...	2·06	11·29	3·45	2·40	30·52	17·44
Nitrogen	·14	·23	·28	·10	1·85	1·07
Calcium oxide	·43	·19	·68	·08	1·80	·16
Magnesium oxide ...	1·39	1·31	1·77	·12	·84	1·12
Potassium oxide ...	·26	·52	1·39	·61	·75	·74
Phosphoric anhydride	·02	·01	·01	·015	·02	·01

1. Mount Misery coral.
2. High-level corals.
3. High-level beach-rock.
4. Pot-hole clay from Castle Grant.
5. Low-level corals.
6. Low-level beach-rock.

How do the characteristics of the high-level soils compare with those of the residua? On page 52 of the 'Geology of Barbados' I wrote :—

The principal differences between the two classes of soils are that the red soils on the upper terraces contain far more iron than do the black soils, while the latter contain the silicates of calcium and magnesium in larger quantities. The red soils also contain a larger proportion of organic matter, humus and root residues, but when the proportions of humus present in the soils were determined, it was found that the red soils contained, on an average, 0·295 per cent., against 0·520 per cent. in the black soils.

These remarks indicate the probable presence of higher proportions of ferromagnesian minerals in the rocks and volcanic debris from which the darker soils of the lower levels have been derived than in those which gave rise to the higher-level red soils; and my recent examinations of the residua from both high and low-level limestones are accordant with this statement.

In the autumn of 1887, in collaboration with the late Mr. George A. Sealy of Buckden, Barbados, I commenced an enquiry, into the compositions of certain of the red soils of the parishes of St. John, St. Thomas, and St. Joseph. Unfortunately my transfer in 1889 to British Guiana prevented the enquiry being completed, but some details of the analyses are on record in my private books. The analyses, as far as my records show, determined the bulk-compositions of the soils and the compositions of their constituents soluble in a large excess of cold 10-per cent. hydrochloric acid (500 c.c. dilute acid to 10 grams of soil) whilst in contact for a fortnight, of the constituents rendered soluble by boiling the soils in excess of 20 per cent. hydrochloric acid as long as any action took place; of those constituents rendered soluble only by the action of boiling sulphuric acid, and of the residues not acted upon during these treatments.

I have consolidated and re-arranged the results of the analyses for my present purpose. They are thus as follows :—

1. Buckden, St. John's
2. Clifton "
3. Mt. Wilton, St. Thomas'
4. Little Island, St. Joseph's (Mr. W. T. Armstrong)

NOTE:—The plan of this investigation was that I was to determine the compositions of the soils and the proportions of their constituents soluble respectively in boiling hydrochloric acid, and in large excess of 10-per cent. hydrochloric acid, normal, decinormal and centinormal hydrochloric, nitric, oxalic, and citric acids, and normal, decinormal, and centinormal solutions of ammonium oxalate, ammonium citrate, ammonium nitrate, and ammonium sulphate, acting in the cold, whilst Mr. Sealy was to record the crops obtained in the fields during several successive years, and to mark any increases or decreases in yields occasioned by alterations in the manurial treatments

High-level Red Residual Soils on Coral-rock, Barbados.

	1	2	3	4
Per cent. of water retained by air-dried soil ..	14·7	10·7	11·9	12·1
Percentage compositions of the soils dried at 105° C.				
Combined water	12·000	10·494	11·662	10 964
(1) Humus	·381	·336	·295	·910
Root and other vegetable debris	2·960	2·098	2 565	3·355
Soluble in water and in cold dilute (10% HCl) hydrochloric acid				
Chlorine	·036	·008	·006	·005
Nitric anhydride	·013	·020	trace	·025
Sulphuric anhydride ...	·141	·057	·166	·155
Phosphoric anhydride ..	·150	·105	·107	·151
Chalcedonic and combined silica (soluble in 20% sodium hydrate solution	25·228	22·702	16·482	4·604
Alumina	6·266	4·319	7·402	6·852
Iron peroxide	10·885	8·243	9·906	8·755
Iron protoxide	·161	·785	·878	·820
Manganese oxide	·161	·140	·142	·159
Calcium carbonate	·334	1·400	2·148	3·752
Calcium oxide (as sulphate and silicate)	1·506	1·098	nil	·609
Magnesium oxide	·485	·343	·307	·328
Potassium oxide	·090	·042	·033	·132
Sodium oxide	·033	·005	·003	·003
Rendered soluble by boiling hydrochloric and sulphuric acids.				
Phosphoric anhydride ..	·030	·184	·114	·072
Silica (combined)	17·866	14·749	20·112	24·732
Titanium oxide	1·994	1·479	2·256	2·778
Alumina	12·961	11·410	15·623	20 694
Iron per xide	·373	1·254	1·090	1·503
Iron protoxide	·760	1 290	·900	·615
Manganese oxide	·055	·053	·027	·025
Calcium oxide	·274	·408	·355	·081
Magnesium oxide	·232	·161	·041	·358
Potassium oxide	·476	·380	·227	·310
Sodium oxide	·344	·158	·312	·144
(1) Quartz (insoluble) ...	3·818	16 215	7·040	7·458
	100·013	99 981	100·199	100 331
(1) Containing nitrogen	·230	·126	·185	·247

It is noticeable that the soils, with the exception of their mean content of sulphuric and phosphoric anhydrides (·130 and ·228 per cent, respectively) are closely accordant in their chemical and physical characteristics with the artificially and naturally separated residua of the coral limestone. That they contain

mineral constituents (silicates) not attacked by cold hydrochloric acid, was proved, as I determined, in the fractions not soluble in cold hydrochloric acid but dissolved by successive treatments with hot strong hydrocholric and sulphuric acids, the proportions of presumably felspathic constituents, the oxides of calcium, potassium and sodium, to be as follows :—

	1	2	3	4
Calcium oxide	·274	·408	·355	·081
Potassium oxide	·362	·304	·184	·195
Sodium oxide	·310	·142	·281	·112

whilst the residua not acted upon by the hot acids consisted of crystalline silica, and of fragments of orthoclase (sanidine ?), and yielded the following to attacks of hydrofluoric acid :—

	1	2	3	4
Potassium oxide	·114	·076	·043	·115
Sodium oxide	·034	·016	·031	·012

thus indicating that the soils contain either fragments of orthoclase and plagioclase felspars, or incompletely weathered debris from them.

Unfortunately I have not any notes as to microscopical examinations of the hot-acid- insoluble residua, but I must have so examined them as otherwise I should not have determined the alkalies in the residua, but regarded these as consisting of quartz alone.

The sulphuric anhydride was probably derived from the amounts added to the soil in the constituents of the manures used—sulphate of ammonia, sulphate of potash, and superphosphate of lime—which in round figures contained 60, 45. and from 16 to 18 per cent. of sulphuric anhydride respectively, and probably supplied each year 245 lb. per acre of sulphuric anhydride, equal to ·011 per cent. of the soil to a depth of 8 inches. Some of the phosphoric anhydride must have been of similar origin to the sulphuric anhydride, but its presence in the soil is in far higher proportions than could have arisen from the manuring used in the eighties, which each year supplied from 36 to 45lb. of phosphoric anhydride per acre, equal only to increases of from ·0017 to ·00-2 per cent. of the soil to a depth of 8 inches. Hence the soil's average content of ·228 per cent. of phosphoric anhydride calls for explanation, as it could not have been derived from the insoluble residue of the coral-rock, nor supplied by the manures applied.

The quantities of the extraneous constituents contained in the coral and limestone rocks, are but very small, and hence considerable thickness of the rocks must have been dissolved to produce even thin soils. The calcitised coral from Mount Misery has been much affected by percolating waters which have

dissolved out some of its original carbonates, and hence its proportion of extraneous minerals is abnormally high, so that it will not be taken into account. Eight characteristic specimens of unaltered limestone examined, contained in parts per 10,000 the following quantities of extraneous constituents: 9, 55, 75, 48, 30, 33, 31, and 22; their mean content per 10,000 parts being 36 parts. Other samples I examined contained much higher proportions, for instance. 184, 232, and 388 per 10,000 of insoluble residua; but as these may have accumulated in the rocks from the weathering of limestones from higher levels or from the globigerina-marls, I have omitted them from consideration.

The specific volume weights of the Barbados limestones have been determined on four characteristics specimens to be as follows:—

			Specific Volume-weight.
1	...	...	2·23
2	...	...	2·01
3	...	...	2·05
4	...	..	2·35
Mean	...	...	2·16

Hence in round figures 1 cubic foot of the limestone of average porosity weighs 135lb. The average weight of a cubic foot of the red-soil is approximately 72lb. A column of the coral-limestone 1 foot square and 10 feet high, and containing ·36 of 1 per cent. of insoluble extraneous constituents would, during weathering, produce ·067 of a foot, or about $\frac{4}{5}$ of an inch, of earth. To produce 8 inches of earth would entail the destr ction by weathering of 100 feet of the limestone-rock.

The mean content of phosphoric anhydride in the acid-soluble fractions of nine characteristic samples of unaltered Barbados limestcn s was determined by me to be ·0123 per cent. On the assumption that the whole of this remains in the resultant soil with the insoluble residua, the mean content of that soil in phos phoric anhydride would be very high—3·49 per cent. Hence it is evident that there is a far more than ample supply of phosphoric anhydride in the coral limestone to give rise to soils with a mean content of ·228 per cent. of phosphoric anhydride. But tricalcium phosphate is slightly soluble in water containing carbonic acid, and hence only a portion of that set free from the coral-limestone during its degradation by the action of such water would be taken up by the insoluble residues and retained in the resultant earth.

At first sight it appears improbable that, as 100 feet thick of coral limestone could only give rise to 8 inches of residual soil, the red soils of the upper levels in Barbados could have been thus formed. When we wrote 'The Geology of Barbados', available evidence indicated that the coral-limestone did not date back earlier than, if as early as, the Pleistocene. But more recent enquiries have led to the conclusion that the highest and therefore oldest of the limestones may date back to the ending of the Pliocene. The degradation of 100 feet of limestone during the vast period of time—say, from one and a half to two millions of years—

thus indicated, is readily conceded, as weathering at this rate does not require the degradation of more than from 0·0006 to ·0012 of an inch of the limestone a year. That it may have taken place is shown to be possible by the erosion of the numerous deep gulleys in the island, and by the detrition and removal of the thick coating of foraminiferal marls and limestones which presumably had formed on the rising surface of the island. Unfortunately I have not satisfactory samples of the globigerina marls and foraminiferal limestones in which to determine the extraneous constituents, but examinations of thin slices of them indicate that they consist in part of minute, sharply angular fragments of felspars, which appear to be present in larger proportionate quantities than they are in the coral limestone.* It is thus probable that the destruction by detrition and weathering of the 50 or more feet of foraminiferal marls and limestones which have largely disappeared from the island, added their quota of ferruginous argillaceous earth to the production of both the high-level and of the low-level soils.

Persons unaccustomed to deal with analytical figures may find it difficult to appreciate from an analytical table the small quantities in which the extraneous constituents are present in the limestone rocks. The following table shows the pounds of each extraneous constituent present in 10,000 lb. of the unaltered limestones I have examined :—

1. High-level coral.
2. High-level beach-rock.
3. Low-level corals.
4. Low-level beach-rock.

	Pounds per 10,000 lb. of limestone				
	1	2	3	4	Mean.
Combined water ...	·9	2·88	1·03	1·49	1 57
(1) Organic matters ...	1 03	1·06	9 4	3·9	3·85
Organic silica	·12	·46	1 4	·75	·68
Quartz	·01	·65	2 79	3 71	3·29
Combined silica	2·71	13·64	7·78	6 04	7·54
Alumina	2 08	6·76	3·57	3·93	4·08
Iron peroxide	1·1	3·88	2·34	1·13	2·11
Iron protoxide	·17	·24	·55	·42	·34
Manganese oxide ...	·03	·26	nil	nil	·07
Titanium oxide	·19	·61	·42	·28	·38
Calcium oxide	·02	·21	·56	·04	·41
Magnesium oxide ...	·12	·56	·26	·25	·30
Potassium oxide ...	·04	·44	·23	·17	·22
Sodium oxide	·11	·11	·58	·16	·24
Phosphoric anhydride ...	·001	·003	·004	·002	·0023
(1) Containing nitrogen	·020	·088	·100	·053	·080

* An analysis I made in May 1882, of a sample of globigerina-marl I had collected in the Bowmanston cave showed it contained 8·7 per cent. of ferruginous kaolin, 10·6 per cent. of quartz with ·6 per cent. of opaline silica. The globigerina-marl here occurs at an altitude of 360 feet above sea-level.

To liberate the whole of these constituents, the following quantities of the soluble parts of the limestone, mainly calcium and magnesium carbonates, must be dissolved and removed :—

1	...	...	...	9,991·3 lb.
2	...	..	...	9,968·2 ,,
3	...	..	...	9,969·1 ,,
4	..	...	...	9,977 7 ,,
Mean	...	...	..	9,976·5 lb.

The proportions of the extraneous mineral fragments which I have been able to separate in recognizable crystalline and glassy forms are very small, the yields per 10,000 parts of the limestone being as follows :—

High level coral, Mt. Misery		...	1·18 parts
High-level corals	...	...	·43 ,,
High-level beach-rock	...	...	1·05 ,,
Low-level corals	...	...	5·60 ,,
Low level beach-rock	...	...	2·10 ,,

The fact that such minute proportions can be easily isolated from limestone and more or less exhaustively analysed, both chemically and petrographically, is of interest.

In one of the criticisms I have quoted of Mr. Hughes' suggestion is the following :—

> The amount of volcanic ash that in recent times has fallen on the island and been added to form the present soil is scarcely worthy of consideration either from its bulk or its power of enriching the island.

The record of the four falls of volcanic ash which took place during the century, 1812 to 1912, show that the following amount of ash, in pounds per square foot, fell :—

Year.			lb.
1812 (May)	...	...	1 46
1902 (May 7) ...	...	...	·96
,, (Oct. 15) ...		...	·22
1903 (March 22)	...	...	·14 (·31 Bovell)
			2·78lb.

The addition of 2·78 lb. of volcanic ash to the upper 8 inches, or 48lb. of soil, through which the roots of such surface-feeding plants as the sugar-cane extend, is, in my opinion, of some importance, and certainly one which cannot be regarded as negligible. It is equal to the addition of the amount of earth which would be set free by detrition and by weathering from a thickness of 5 7 feet of the limestone to each square foot of soil, or, say, the normal contribution of 85,000 years

It is clear to me that the genesis of the high-level Barbados soils is and has been the weathering from the limestone, of air-borne volcanic minerals, possibly also of ferruginous clay which had been held in colloidal suspension or solution in the ocean waters from which the coral-rocks had their origin, and also of argillaceous and limonitic matters contributed by the wearing away and weathering of the globigerina-marls and

foraminiferal limestones, and that these gradually accumulating residues have been added to during geological and historical times by showers of volcanic debris from one or other of the vents of the south-eastern West Indian volcanic Province.

The origin of the low-level chocolate and black soils is similar, but they contain, in addition to debris of purely volcanic origin, derived either directly from their underlying limestone and from later showers of ash, or indirectly from the surface-wash of the higher limestone terraces, detrital matter washed from exposed strata of the Oceanic and Scotland Series during the slow elevation of the lower districts of the island.

The very sharply angular outlines of the minerals I have separated from the corals indicate that these minute fragments have undergone very little change since they fell on the slowly extending coral-rock; whilst those I isolated from the Castle Grant pot hole clay show by their rounded-off outlines, and their dulled and corroded surfaces, that since their liberation from the limestone by the solution of its carbonates in water containing carbonic acid percolating into the limestone for its earthy cover, the minerals have undergone some of the weathering and lateritic changes which finally result in the production of very finely divided ferruginous clay. The position of the mineral fragments in the earth immediately above the porous limestone is exceptionally favourable to the production from them of such clays. Practically all the clay produced during the action of kaolinisation and lateritisation is filtered off from the soil-waters on the surface of the underlying porous limestone, and hence the slow weathering of the volcanic minerals results in the formation of the almost impervious layers of clay resting on the actual surface of the rock, which, in the higher parts of the island, not infrequently render deep forking and ploughing for *subsoil drainage* purposes, matters of great importance.

I trust that this paper not only clearly indicates the origin, directly or indirectly, of the Barbados soils from the air-borne debris of the volcanoes of St. Vincent, and possibly of the Grenadines and other vents of the West Indian volcanic Province, but recalls to many of the members of the Barbados Agricultural Society, the marked scientific acumen of its Consulting Chemist, George Hughes, F.C.S., to which Barbadians were so deeply indebted for the great increase which took place in their sugar crops during the decade 1880-1890.

NOTE ON THE OCCURRENCE OF RHYOLITIC PEBBLES IN ANTIGUA.

Running across the island of Antigua from north-west to south-east, not far from the base of the limestone hills, there is a bed of coarse gravel consisting of water-worn pebbles and sands the origin of whch is obscure, as is also its relation to the general geology of the island. The bed appears to be unconformable to the pleistocene water-deposited tuffs on which it rests; it has long been noticed that the rock materials of which the pebbles are composed are unlike any rocks yet recognized as occurring in Antigua.

In his paper on the geological and physical development of Antigua, published in the *Quarterly Journal of the Geological Society*, London, Vol. LVII, p. 500, Dr. J. W. Spencer describes this deposit under the name of the Cassada Garden Gravels as follows:—

'Cassada Garden estate is situated about 2 miles east of St. John's, on the eastern margin of the tuffs Consequently it is somewhat distinctly removed from even the newer volcanic rocks of Drew's Hill. At the mill on Cassada Garden estate is a low eminence rising only about 20 feet abve the plain. A chain of similar mounds extends south-eastward. These are composed of somewhat coarse, perfectly water-washed pebbles of igneous rocks, with fresh, compact, undecomposed surfaces. In section, at the pond of Cassada Garden, the gravels are seen to be interstratified horizontally with loam. Mr. (now Sir Francis) Watts who kindly took me to this locality, had examined the section shown in a well, sunk through the deposit, and found that it did not exceed 20 feet in thickness, or precisely the height of the knolls above the plain. The gravel knolls do not attain an elevation of more than 50 to 75 feet above the sea. These deposits, transported from considerable distances, and accumulated by currents, have also suffered denudation. The whole series resembles sections of the Columbia formation of America, the Zapata of Cuba, and the Liguanea of Jamaica, which belong to the early part of the Pleistocene Period.'

Specimens of these pebbles were forwarded by the Imperial Commissioner of Agriculture for the West Indies, to Prof. J. B. Harrison, C.M.G., Director of the Department of Science and culture, British Guiana, who reports on them as follows:—

'All are igneous rocks, but not of the prevalent West Indian types as I know them. The following are descriptions:—

'No. 1. *A somewhat coarse-grained greenish pebble.* Phenocrysts of plagioclase and of orthoclase, the former showing zoning, with here and there a bleb of quartz showing corroded and eroded outlines in a spheroidal felspathic matrix containing some minute specks of epidote and of magnetite. The green colour is due to chloritic products or "viridite" bordering some of the spherulites. The rock is veined with secondary perlitic opaline matter. *A spherulitic rhyolite.*

'No. 2. *A fine-grained green pebble.* A micromosaic of very confused minute grains of felspar and quartz with very abundant

granules of epidote and some patches of secondary quartz. *An epidotised rhyliote or felsite.*

'No. 3. *A somewhat coarse-grained buff-coloured pebble.* Clouded phenocrysts of orthoclase in a confused micro-granitic matrix of felspar and quartz, in places micropegmatitic; containing some minute brown specks of limonitic iron ore, a few minute specks of epidote, and a very few specks of magnetite. *A Rhyolite.*

'No. 4. *A fine-grained buff-coloured pebble.* A few coloured phenocrysts of orthoclase and some large phenocrysts of rounded and corroded quartz in a confused microcrystalline matrix of felspar in places spherulitic, and containing minute specks of magnetite with diffused limonite. *A spherulitic rhyolite.*

'No. 5. *A brownish-red, fine-grained pebble.* Angular phenocrysts of orthoclase and plagioclase felspar in a confused microcrystalline matrix coloured by exceedingly minute grains of hematite. The felspar phenocrysts are largely sanidine. *A Rhyolite.*

'No. 6. *A purple pebble, weathering white on its surface.* Small orthoclase and plagioclase phenocrysts, many of the former with corroded outlines in a confused in parts spherulitic matrix of minute grains of felspar and quartz with specks of brownish iron-ore, some diffused limonite and a few specks of magnetite with patches of "viridite." *A Rhyolite.*

'No. 7. *A dark purple pebble showing small blebs of quartz.* Numerous large phenocrysts of quartz with corroded outlines and of orthoclase and of plagioclase with more or less rounded outlines in a microcrystalline matrix of very minute grains of quartz and of felspar with many minute specks of magnetite. *A Rhyolite* or *Quartz-porphyry.*

'No. 8. *A black, very fine-grained pebble.* Some corroded phenocrysts of a colourless augite, others of orthoclase and of plagioclase in a confused andesitic groundmass of very small felspar prisms with minute specks of magnetite. Some secondary colourless spherules of zeolite, and some patches of epidote have developed in the matrix. *An Augite-andesite.*

'No. 9. *A red opaque pebble.* An opaque, red "Jasper," veined with quartz.

'Nos. 1 to 7 are rhyolites, of types not infrequently described as quartz-porphyry and as quartz-felspar-porphyry. They have not the structure of surface lavas but of intrusive rocks. The plagioclase phenocrysts are of the albite-oligoclase family.

'There are not any rhyolites from the West Indian province in the collections of West Indian igneous rocks made by Franks and myself. The nearest we have to these persilicic or acidic rocks are trachytes from the Morne and from Piton Flore of St. Lucia, and even these are more closely related to No. 8 than to the other of your specimens. But I have several specimens of ancient (Pre-Cambrian) rocks of this type from the Berbice River which closely resemble Nos. 4 and 7.

'In my opinion only closely searching field-work aided by microscopical study is at all likely to decide the problem of

where these rhyolytes or quartz-porphyry pebbles were derived Although resembling in character and composition the Berbice quartz and felspar porphyries, they do not show the signs of secondary silication the Berbice ones as a whole do.

'Iddings, in Volume II of his recent work on Rocks, states on p. 459 that "rhyolite" occurs in Cuba, whilst on page 460 he mentions, in connexion with the Lesser Antilles—Saba to Grenada—" no rhyolites," and states of their igneous-rocks that "distinctly alkaline and quartzose varieties are scarce or are absent" ; but, in connexion with the paper on the origin of the Barbados soils, I have recently examined some of the volcanic ash beds in the lower strata of the Oceanic Series, and found that they consist of persilicic pumice which must have been derived from a similar or possibly the same magma as the Antigua pebbles.'

More recently Professor Harrison writes: 'a high authority on petrology, Dr. J. A. Grutterink, Professor of Economic Geology and Mineralogy at the Technical High School at Delft, Holland, who passed through here whilst returning from an official visit to Dutch Guiana, examined the micro-slices of the Antigua pebbles. He gave as his opinion that the great majority of these pebbles were " typical rhyolite ", and agreed with my determinations in every respect. After due consideration he said that only a tectonic geologist would be able to account for the presence of these pebbles of rhyolite in Antigua.'

It seems of interest to record in the *West Indian Bulletin* the occurrence of rhyolites in the Antigua pebble beds, as later enquirers may be led to tackle the problem of their origin.

TROPICAL DEPARTMENTS OF AGRICULTURE WITH SPECIAL REFERENCE TO THE WEST INDIES.

BY SIR FRANCIS WATTS, K.C.M.G., D.Sc.,

Imperial Commissioner of Agriculture for the West Indies.

The following paper was read at a meeting of the Colonial Section of the Royal Society of Arts held on February 3, 1920; Lieut-Colonel Sir David Prain, C.M.G., C.I.E., LL.D., F.R.S. Director of the Royal Botanic Gardens, Kew, being in the chair.

The paper together with the discussion following the reading of it, was published in the issues of the *Journal of the Royal Society of Arts* for February 20 and 27, 1920, and is here reproduced :—

Tropical departments of agriculture have arisen by an interesting process of evolution, in which the West Indies have been concerned to no small extent.

The geographical discoveries of the fifteenth and sixteenth centuries led to great interest being taken in the various plants and products found in newly discovered countries, while the desire to colonise these countries, was accompanied by the natural tendency to cultivate many of the plants then found for the first time, or then first made familiar as the source of commodities which had for some time reached European countries through devious channels, such as the caravan routes of the East, or trade routes through the Red Sea.

In addition to cultivating the plants found in different countries, much effort was expended on attempts to introduce desirable plants into some of the new-found countries, and in this way there arose such epoch-making introductions as that of the sugar-cane from the Eastern to the Western world, tobacco, maize, potatoes, and other products from the West to the East, together with such carefully planned efforts as were involved in the introduction of the bread-fruit from the Pacific to the West Indies, and the mango from the East also to these islands. Mere enumeration of the work done in this way would occupy the whole time of an evening's discourse.

When making introductions of new plants into new countries it soon became obvious that success could only be attained if proper provision were made for their care, at least until such time as they were propagated in such numbers as to become well established and well diffused locally. In this way there arose botanic gardens in tropical countries, whose first care was to receive such plant introductions as had been already decided upon, but which in turn soon reacted on the outlook, for those in charge of these gardens occupied themselves with the constant inquiry as to what plants could be collected and introduced into their gardens, largely with a view to ascertaining what new plants were capable of being grown in the new surroundings, and also to ascertain whether some, or many, of these would be capable of being grown commercially for profit.

At the same time, posterity owes much to the mission gardens which the early missionaries established around their stations; these served both as active centres for the introduction, acclimatization and distribution of new plants, and also as centres whence the knowledge of the best manner of treating these introductions was disseminated amongst those into whose hands the new plants fell.

Considerable activity was displayed in these matters in the West Indies. A botanic garden was established in St. Vincent as early as 1764, and maintained until about 1830, when a number of such plants as could be moved were transferred to the botanic gardens at Trinidad It is interesting to note that in 1772 the Royal Society of Arts awarded a gold medal to Dr. Young, who was then in charge, in recognition of the flourishing state of the garden. This garden played an important part in connexion with plant introduction into the West Indies, for Captain Bligh placed here some 300 bread-fruit plants which he had brought from Tahiti: nutmeg, cinnamon and clove trees were also introduced into this garden; and to this place also, Lord Rodney sent some of the mango and cinnamon plants which he took from a French man-of-war in 1792.

A botanic garden was also established at Bath, in Jamaica, in 1774. Various plants were brought there from Tahiti by Captain Bligh, amongst which were four varieties of sugar-cane, as well as the bread-fruit and other plants. After many changes and vicissitudes in the history of these early gardens, botanic gardens, conducted on similar lines to those with which we are now familiar, were established in the West Indies, in Jamaica and Trinidad.

The closing years of the nineteenth century were critical ones as regards the agriculture and commerce of the British West Indies; up to that time most of the islands had been dependent upon sugar as the mainstay of their agriculture and commerce; sugar was the dominant factor in most of them; it was so in the larger colonies, such as British Guiana, Trinidad and Jamacia, as well as in Barbados, Antigua and St. Kitts; while even those islands like Grenada, St. Vincent, St. Lucia, Montserrat and Nevis, where sugar cultivation is now relatively unimportant, then depended mainly upon that industry. The period about 1883 was critical for the West Indian sugar industry, as the price of sugar fell to a point at which its production was no longer remunerative. In some of the islands where the disadvantages were most marked, the sugar industry so declined that in a few years but little sugar was being produced in such islands as Grenada, St. Vincent, Montserrat and Nevis, in most of which other industries had been substituted, as cacao in Grenada, arrowroot in St. Vincent, and limes in Montserrat and Dominica. The sugar industry was, however, maintained in a struggling condition in the more favourably situated islands of Barbados and St. Kitts, while it appeared to be moribund in Antigua.

It is not necessary to enter at length on the causes of the decline of the British West Indian sugar industry; suffice it to say that the main reason was the competition of the beet-sugar industry of the continent of Europe, aided by the very unfair system of State bounties there in vogue, whereby the sugar producers of Germany and Austria, and, to a less extent, of France, received sums ranging from £1 or £2 per ton up to, at one time, as high as over £5 per ton, for the mere act of dumping sugar into Great Britian, and this at a time when the market price of West Indian raw muscovado sugar, the type then principally made, ranged from about £7 10s. to £9 per ton. Under the fiscal system then in vogue in the United Kingdom there was no measure of protection against this condition of affairs, and the sugar industry of the West Indies would have been extinguished but for the fact that the tariff conditions in the United States permitted the importation of British West Indian sugar at moderate rates of duty, while imposing upon sugars receiving foreign bounties, additional rates of duty equivalent to the bounties.

This great decline in the value of sugar led to serious consideration of the economic prospects of the West Indian colonies; this took the form of an inquiry into the possibility of so improving the method of growing the canes and manufacturing the sugar as to enable the West Indian sugar industry to compete with the beet sugar produced in Europe. Adverse

fiscal conditions, however, retarded the progress in this direction for many years, and led to investigations which will be referred to later.

In addition to attention being directed to the condition of the sugar industry, much thought was given to the possibility of introducing other industries which might tend to support some, at least, of the colonies, even were they not able entirely to take the place of sugar.

In 1885 Sir Joseph Hooker, commenting on the Report of the Royal (West Indian Finance) Commission, appointed in 1883, expressed the opinion that there could be no doubt that the future prosperity of the West Indies would be largely affected by the extension to other islands, unprovided with any kind of botanical establishment, of the operations so successfully pursued in Jamaica (*Kew Bulletin*, 1887. Pt. 6, p. 6). This may be taken as the starting-point in a line of policy which has considerably affected the West Indies.

In 1884 Mr. (now Sir) Daniel Morris had submitted to the Colonial Secretary of Jamaica proposals for the formation in each of the smaller British West Indian colonies of small botanical establishments, which should be placed under the direction of some local officer, the provision of skilled scientific officers hardly being contemplated, and that they should serve as centres from which there could be distributed such plants as might be successfully introduced and have consideration as the basis of new industries.

The idea underlying the proposals was that the Botanical Department at Jamaica should serve as a central institution; that it should supply to the subsidiary stations such seeds and plants as were available, which it was thought it might be desirable to introduce. It was contemplated that the central establishment would only communicate with the recognized officer in each colony thus associated, who would forward requisitions and transact all business as between the local and the central establishment. It was suggested that 'the control of each station would be entirely in the hands of the local government; the connexion with the central establishment would be confined to dealing with applications for seed, plants, or other purposes of a purely consultative character.'

At the same time it was suggested by the then Assistant Director of Kew, Mr. (now Sir) W. T. Thiselton Dyer, that in addition to distributing plants, the central institution should organize a regular system of botanical bulletins containing practical hints as to the treatment of economic plants, and the conditions under which they might best be utilized in developing remunerative industries.

With a view to giving effect to these and cognate suggestions, general proposals were addressed in February 1885, to the Governors of the several West Indian colonies, including the Bahamas and British Honduras, strongly recommending the adoption of the scheme. In consequence of the transfer of Mr. Morris from the post of Director of the Botanical Department of Jamaica to that of Assistant Director of Kew, together with various other changes and obstacles to progress, some delay was experienced in putting the whole scheme into operation. A

botanic garden was, however, established in Grenada in 1886, and about the same time a small appropriation was made by the Legislature of Barbados for the purpose of forming a botanic station in connexion with the boys' reformatory at Dodds, where experiments with sugar-canes had already been started on a fairly extensive scale under the direction of Professor Harrison, with whom was associated Mr. J. R. Bovell. This was the first experiment station as such in the West Indies, and from it have originated many of the varieties of sugar-cane now most widely under cultivation. In the same year the botanic garden at St. Lucia was established, and in 1890 that of St. Vincent was revived.

In order to stimulate and aid the work thus initiated, Mr. Morris, the Assistant Director of Kew, was, at the request of the Secretary of State for the Colonies, entrusted with a mission to visit the several West Indian islands. An interesting account of this mission is recorded in the *Kew Bulletin* for 1891, pp. 103-68.

As the outcome of these efforts, botanic stations, or gardens, were established in Antigua (1890), St. Kitts (1891), Dominica (1890), and Montserrat (1890), while a chemical laboratory, largely devoted to the consideration of agricultural problems, was established in Antigua in 1889.

This period marks a definite advance towards the development of scientific agriculture in the West Indies. The botanical establishments thus created were closely associated with Kew, which was largely responsible for the movement which led to their formation, and for the ideas and principles on which their work was based. They were maintained by the several local governments with varying degrees of interest and financial support. These establishments marked the transition period from botanical establishments to experiment stations; they were useful in that they paved the way for later developments.

The general economic conditions of the West Indies became steadily worse in the years immediately following these efforts. The price of sugar declined steadily, and there seemed to be no prospect of its improvement. The production of sugar dominated West Indian affairs, and as the prices of other commodities such as cacao, arrowroot, and lime juice also showed declining tendencies, there was great apprehension as to the future, the public finances of practically all the colonies being in a straitened condition. As a result of these conditions much difficulty was experienced in obtaining adequate appropriations for the botanical establishments.

This alarming state of affairs throughout the British West Indies led to the appointment, at the close of 1896, of the West Indian Royal Commission to inquire into the conditions and prospects of the sugar-growing West Indian Colonies. The Commission visited practically all these colonies in 1897, and reported in the same year.

The report distinctly marks a period in West Indian history, and should be freely consulted by all who desire to form a sound opinion on the state of West Indian affairs at that time

The Commission clearly recognized that the colonies in question were dependent upon agriculture and must remain so dependent; the sugar industry they saw was dominant, though they feared it would be moribund unless drastic steps could be taken to save it. This industry seemed to be almost the only one suited to the conditions of many of the islands, but it was felt that something definite should be done to ascertain whether other agricultural industries might not be encouraged and developed to such an extent that they might become the mainstay of those colonies in which sugar cultivation gave least promise of being successfully revived. In this the colonies were confronted by lack of information and by lack of means to secure and apply such information as might be available.

As the outcome of this investigation and report, definite recommendations were made for the creation of an Imperial Department of Agriculture, to be supported entirely from Imperial funds. These proposals received the whole-hearted support of Mr. Joseph Chamberland, then Secretary of State for the Colonies.

Time does not permit of anything but the briefest statement concerning the constitution and work of this Department, but an appreciation of the manner in which it originated, how it was supported, and what it has done, is essential to an understanding of the present position of agricultural department in the West Indies, and possibly those of several other tropical possessions of the Empire.

The Imperial Department was inaugurated in October 1898, Mr. (now Sir) Daniel Morris being appointed Imperial Commissioner of Agriculture for the West Indies. In planning his work Sir Daniel Morris wisely built upon existing organizations; he found a good foundation ready to hand in the botanic gardens and kindred institutions, which had been evolved, as already stated, largely as the result of efforts and recommendations with which he had been intimately concerned. These institutions had, however, been lamentably stunted and starved from lack of funds, and from the limited outlook of the local legislatures and other authorities upon whom they depended for support.

An appropriation amounting to some £17,500 a year was made available from the Imperial Treasury, and the Imperial Commissioner established his headquarters in Barbados; he speedily got to work in inquiring into the capabilities of the agricultural organizations in all the colonies, cognizance being taken of the botanic gardens, the chemical laboratories, and all the existing institutions likely to have a bearing on agricultural development, not forgetting the schools of various grades. The work which all these agencies had been carrying on in the past was studied, and plans made for continuing what was promising and useful, and for extensions in new directions. It is important to recognize this continuity of effort, for it justifies the line of activity taken by Kew and by the several Colonial Governments in the time prior to the creation of the Imperial Department, and demonstrates the value of continuity of policy when once the policy agreed upon is soundly chosen. The absence of continuity of policy in colonial government may be held to be responsible for slow development in many directions,

and in this, as in many other respects, the Imperial Department may well claim to have demonstrated much that is useful in administration.

The work of the Imperial Department in the earlier years consisted in assisting the local governments to put their agricultural institutions into better order; for this purpose grants-in-aid were made to every West Indian government. In the larger colonies, including British Guiana, Jamaica, and Trinidad, the grants were supplementary to the expenditure of the local legislatures, and they served in no inconsiderable degree to stimulate the work of the agricultural organizations and to keep their work in line with that carried on in the smaller colonies where the Imperial grant-in-aid entirely supported the various activities of the local departments of agriculture which were created or consolidated, as the outcome of the fostering care of the Imperial Department. It is important to recognize that this action had the effect of definite local departments of agriculture being formed out of the poorly equipped and somewhat indeterminate institutions which existed at that time in most of the islands, particularly in the smaller ones.

The money appropriated for this purpose was, in every cases treated as a grant-in-aid to the colony receiving it; it was expended on recommendations made by the Commissioner in consultation with the local executive, and duly voted by the several legislatures concerned as part of the approved expenditure of colonies

This condition obtained until 1909—that is to say, for ten years—during which time the cost of maintaining the local departments of agriculture in the smaller colonies was borne entirely by the Imperial Government, while material assistance was given to those in the larger colonies.

At the expiration of this time, in view of the improved condition of the colonial finances, largely as the outcome of the agricultural development fostered by the work of the Imperial Department, progressive diminution of the Imperial grants to the colonies was decided upon, and it was agreed that these grants should be diminished year by year, until they ceased in 1912-13.

All this time financial provision was made from Imperial funds for the Imperial Commissioner of Agriculture, together with his staff at headquarters, and also for the cost of the maintenance of the office and laboratories at headquarters, and for travelling expenses and for the issuing of various publications.

This condition is maintained up to the present time. I may perhaps, here add that, as the result of my experience, I feel that this is a condition essential to success, and that any attempt to depart from it will be detrimental to the interests of the work as a whole.

In this manner the following amounts have been granted to the several colonies in the years between and including 1898-9 and 1912-13, when the grants-in-aid ceased:—

	£	s.	d.
British Guiana	3,852	14	0
Trinidad	3,563	9	4
Jamaica	2,265	1	0
Barbados	20,044	9	4
Grenada	6,359	19	11
St. Vincent	16,072	16	8
St. Lucia	12,731	17	8
Dominica	15,120	14	5
Montserrat	6,911	16	11
Antigua	10,329	19	1
St. Kitts-Nevis	12,341	8	5
British Virgin Islands	6,692	6	4
Leeward Islands Federal	15,089	13	5
Total grants	131,376	6	2

These amounts are exclusive of the expenditure upon the central establishment.

The creation of the Imperial Department of Agriculture and its assistance in directing the affairs of the botanical establishments which had been evolved in the several colonies, had the important effect of causing these institutions to be regarded definitely as agricultural departments, and not merely as botanical institutions. The change of outlook is important, for it implies that the departments are now expected to have regard to all that pertains to agriculture in the respective colonies; the work is expected to extend much beyond the introduction of new plants and the making of suggestions for their application in possible new industries: it is expected to take into consideration all this, together with the ability to advise concerning the cultivation of staple crops, and the manufacture and manipulation of agricultural products, to have regard to general agricultural economies, and to give consideration to matters of education in so far as these have a bearing on the welfare of agricultural communities. This changed outlook affected the relationship between the agriculturists and the officers of the departments; there has resulted greater intimacy in their relations, and more effective and continuous interchange of ideas and opinions, so that the work of the departments has influenced in a marked degree the agriculture of most of the colonies.

But beyond that there has been important effect on the several governments, which now recognize more thoroughly than before that agricultural matters from an important, integral part of colonial administration, and that the maintenance of other departments, such, for example, as those concerned with public works or public health.

The work of the Imperial Department of Agriculture has thus two principal phases: it is concerned with the affairs of the larger colonies—British Guiana, Trinidad and Jamaica - in so far as its availability for advice in a general capacity is concerned The connexion with the smaller colonies is more intimate, and the Department exercises a more detailed and general supervision

in agricultural matters in these colonies. It is understood that each of the larger colonies is able to maintain a scientific staff, including such technical officers as chemists, entomologists, mycologists, botanists and others, and is able to deal with its own scientific problems in detail. The case is different in the smaller colonies, for the cost of providing such fully equipped staffs in each of these islands would create a disproportionate charge which the revenue would be unable to bear.

To meet these conditions, scientific officers are maintained on the staff of the Imperial Department of Agriculture. These officers are ordinarily resident in Barbados, but they travel as occasion demands. To them is entrusted the investigation of such matters as transcend the scope of the activities of the officers of the local departments. To a considerable extent these officers have been concerned in investigating the several plant pests and diseases which are of fundamental importance to agriculture in the tropics, and which cause serious losses and retard progress in the islands concerned, even to the extent, in some instances, of making it impossible to carry on the cultivation of certain crops unless the pests and diseases can be adequately and economically controlled. Reference will be made later to some of the main features of the lines of activity here outlined.

Agricultural activity was thus stimulated in all the West Indian colonies; the greater extent of the scientific work, the increased number of investigators, the interchange of ideas and opinions, produce their natural effect, so that increased scientific activity in relation to agriculture was soon observed in all the colonies, both large and small. The activity of the Imperial Department thus reacted on the colonies of British Guiana, Trinidad and Jamaica, as well as on the smaller colonies.

As the Imperial Department is more intimately concerned with the details of development in the smaller colonies, it will be convenient now to centre attention more particularly upon some of the work done in these smaller islands, as exemplifying the results attained through the application of scientific principles to agricultural administration, using this expression in the broadest sense so as to include the functions of general government as well as the activities of the agricultural officers and the planters.

It is necessary to understand what are the salient industries of the different islands. To quote the Report of the West Indian Royal Commission of 1879, p. 3, 'the prosperity of the West Indies in former times was mainly due to sugar and rum; the production of these commodities attained such dimensions as to dwarf, and at one time, almost to extinguish, every competing industry.' Sugar production remains the principal industry of Barbados, Antigua, and St. Kitts, and constitutes an important item in St. Lucia. Up to quite recent times it was the main industry of Grenada, St. Vincent, Montserrat and Nevis, and was carried on in Dominica and the British Virgin Islands. Of late the cultivation of cacao has succeeded that of sugar in Grenada, and to a smaller extent in St. Lucia and Dominica. The cultivation of limes is now the principal industry of Dominica, and one of considerable importance in Montserrat and

St. Lucia. In St. Vincent, the cultivation of arrowroot has an important place, while quite recently, and largely as the outcome of the work of the Imperial Department of Agricultture cotton has become the principal industry of St. Vincent, Montserrat and Nevis. Cotton is also important in St. Kitts, and to a lesser extent in Antigua and Barbados, while it has become of value to the peasant cultivators of the British Virgin Islands.

With the establishment of the Imperial Department of Agriculture, and its financial assistance to maintain the local departments, a good deal of interest centred in sugar production. Experiment stations for the study of field problems had already been established in several of the islands; increased financial assistance was forthcoming for these, and their work was extended. Problems relating to the manuring and the cultivation of sugar-cane were investigated and some useful points elucidated; the work of producing new seedling sugar-canes, which had been successfully carried on in Barbados for some years, was extended, new seedlings of promise were distributed to other islands, and on a smaller scale the work of producing new seedlings was undertaken in Antigua and St. Kitts. Here it should be stated that there was much activity on the part of the Agricultural Department of British Guiana in the production of new seedling canes and in the study of their characters, and also in investigating the manurial requirements of the sugar-cane and in studing certain soil problems, some of them of peculiar difficulty.

Much activity was centred in investigations concerning the pests and diseases of the sugar-cane; this aspect of the work was highly appreciated, for in the period about 1895-97 an outbreak of a virulent fungus disease, now known to be due to *Colletotrichum falcatum*, caused the almost complete extinction of the Bourbon cane, the variety then most extensively cultivated. and gave the gravest alarm to sugar-growers, who feared the total loss of their industry. Relief from the trouble was found in the fact that some of the varieties cultivated in the experiment stations—some of which had already passed into general cultivation—were found to be resistant to this disease, so that the danger was arrested by the general adoption of these resistant varieties. It will be readily understood that some time and effort were expended in ascertaining and demonstrating these facts, and that while this work was in progress grave anxiety prevailed amongst the growers of sugar. This position caused additional attention to be centred upon the production of new seedling sugar-canes, with a view to securing resistant canes with a maximum yield of sugar.

It may be claimed that the various pests and diseases of the sugar-cane, together with the means of controlling or mitigating them, are now fairly well understood. Some work still remains to be done in this direction, and this continues to engage the attention of the scientific officers.

As the outcome of all these efforts, the sugar-growers in the several islands are informed concerning the main principles involved in the cultivation and manuring of their canes, and in controlling the pests and diseases to which they are exposed. They thus carry on their operations with a greater sense of security, a security which is felt to be all the safer from the

knowledge that in their midst there is a body of men whose function it is to watch carefully for approaching danger and devise means for fighting it. It is only right that attention should be drawn to the fact that in this and similar work many of the planters themselves have co-operated, and by their co-operation have hastened the progress of knowledge.

In addition to giving consideration to field work connected with sugar, the creation of the Imperial Department, with its financial assistance to the associated departments, made it possible to extend attention to factory problems. Up to the time of the creation of the department, the manufacture of sugar in all the smaller islands, including Barbados, was carried on in small factories making muscovado sugar; that is to say, the sugar was made by means of open pans heated directly over open fires, whereby a soft, brown sugar having relatively small crystals was made. An important and intrinsic defect of these small factories was that the mills used for crushing the canes were, as judged by modern standards, small and inefficient; they had but three rollers, and were capable of expressing only about 50 to 60 per cent. of juice from the canes, or even less in the case of very bad mills, such as existed in some of the islands; this would be equivalent to about 62 to 75 per cent. of the juice contained in canes of average quality. The quantity of cane required to make a ton of muscovado sugar was not accurately known, for the canes were seldom, if ever, weighed. Such estimates as have been made place the amount at some 13·5 to 14 tons of cane per ton of sugar under moderately favourable conditions, but in badly equipped works the amount must have been greater. The actual amount would, of course, depend on the quality of the cane, which varies. In this connexion it must not be forgotten that a certain amount of molasses was produced in conjunction with the muscovado sugar; the value of this varied, the product at times selling at good prices, at others being disposed of with difficulty. Still, on the whole, it was an important factor in the muscovado sugar industry.

For many years there had been much discussion with regard to adopting improved methods of sugar-making, for muscovado sugar was being disposed of with increasing difficulty; the refiners, who purchased by far the larger part of it, were showing marked preference for the types of sugar produced in vacuum pans. Some attempts had been made to adopt modern methods in British Guiana and Trinidad, but in Barbados, Antigua, and St. Kitts this effort had gone little beyond the introduction of vacuum pans in a few cases; the mills still remained of the inefficient three-roller type. In spite of much discussion little progress was made.

The inadequacies of the muscovado system, and the necessity for the adoption of the methods of modern factories, were the subject of much consideration on the part of the agricultural departments in the Leeward Islands, particularly in Antigua, and at last the Antigua Sugar Factory Company took advantage of a favourable opportunity that occurred and created a sugar factory on modern lines at Gunthorpes in that island. In order to secure the erection of this pioneer factory, and to ensure that its results should be available for the guidance of others similarly

situated, financial assistance was given by the Government to the extent of £15,000. The factory as originally put down was a very modest affair, but its work was conducted on strictly scientific lines, and the results, including the figures obtained in the factory and its laboratory, were regularly submitted to the Agricultural Department, which in turn rendered considerable assistance in the way of scrutiny and advice.

It was soon found that the general ideas with which the factory was planned were sound, but that much more had to be done in order to make it really efficient when judged from modern stand points. Seeing that those who had embarked on the enterprise soon felt confidence in their venture, for it was under scientific supervision and its capabilities were becoming apparent; progress was steady and rapid. Time will not permit of anything like a detailed survey of the development of this factory; suffice it to say, that from the first crop of 1,634 tons manufactured in 1905, and 2,349 tons in 1906, the output of the factory had grown to 12,371 tons in 1916, the output for the succeeding years being somewhat smaller on account of drought and adverse growing seasons, which restricted the production of canes.

The progress of the factory can be measured from one or two salient figures: in the early days of the factory's working only some 65 per cent. of the sugar in the cane found its way to market in the form of commercial sugar, whereas in the later years this has reached 88 per cent., refiners' crystals of 96° polarization being made. This constitutes a gain in production of twenty-three on the hundred parts of sugar in the cane, but it is over 35 per cent. on the 65 per cent. recovery of the earlier years. At the same time the quantity of cane taken to make a ton of sugar was reduced from about 9¾ tons to about 8¾ tons, a comparison which is, however, less accurate and of less importance on account of the varying nature of the quality of the canes. It should be added that a fourteen-roller mill was installed in the factory in 1911, and to this much of the improvement in recovery is due.

The Gunthorpes factory has thus served to demonstrate the possibilities of modern sugar-making in small places, and it has shown that a high degree of efficiency can be secured in what must, according to modern ideas, be regarded as quite a small factory. It may be well to state at this point that a factory of this size probably represents the limit of smallness for efficient working. The tendency is towards much larger facrories, even to ten times the capacity of Gunthorpes.

It is worth noting in passing that this factory is based on co-operative principles under which the assistance of outside capitalists was invoked, and they entered into contracts with the owners of sugar plantations to supply canes on a profit-sharing basis for a period of fifteen years; at the expiration of this time, during which the debentures representing the principal portion of the capital of the venture were being repaid, the original contracting plantation owners received shares from the factory equal in number and value to the original capitalists' shares. It should be added that in the process of the expansion of the factory it was joined by other contractors who do not

The period of the fifteen years of the original contract has now expired, and the distribution of the shares to the original contracting proprietors will have been made by the time this paper has been read.

It is satisfactory to note that this contract, which included some features unfamiliar to previous West Indian experience, has worked without a single hitch, and that the factory was paying its way and demonstrating its economic soundness with the low prices of sugar that were realised prior to the war. The high prices obtained for sugar, as the result of the sugar shortage caused by the war, have added considerably to the profits, but the soundness of the principales on which the factory was founded and the relief which these were capable of affording to the sugar industry of the West Indies were demonstrrted under pre-war conditions.

The influence of the Antigua sugar factory was not confined to that island, the information gained in its operation being widely disseminated and thoroughly discussed, as was the intention of the Government in giving it financial aid; in consequence of this the development of similar factories was considered in other islands. As the outcome, a well-equipped factory was established in St. Kitts, reaping its first crop in 1912. This factory is financed by the same group of capitalists as the Antigua one, and is operated on very similar principles with slight modification. The St. Kitts factory has manufactured as much as 11,843 tons in a single season.

Encouraged by the success of the factories in Antigua and St. Kitts the same group of capitalists purchased in 1913 the large sugar factory in Trinidad, known as the Usine Ste. Madeleine, with the plantations connected with it. This concern was in financial difficulty, and its future was very obscure. The knowledge gained at Antigua and St. Kitts proved of the greatest service, and the working of the factory was soon put on a sound footing. This, coupled with some good fortune and the improvement of the sugar position, has resulted in considerable financial success, which has been greatly to the benefit of the colony.

The progress of events connected with the Antigua sugar factory, aided by the publication and discussion of the results obtained, was followed closely by the plantation owners of Barbados. In a short time substantial improvements were made in the small sugar factories of this colony, and several small factories were established, embodying modern methods of sugar production, including the adoption of multiple crushing of the canes in the mills. Notwithstanding the fact that these factories are for the most part quite small, when judged by modern standards, they are reasonably efficient, since, as a rule, they have been evolved out of factories already in existence, and it has been possible in the majority of cases to effect the developments economically and with local capital. These small factories are in a very strong position, though it is is probable that, as developments ensue, there will be amalgamations whereby larger factories will result, which will admit of greater efficiency and diminished cost in production. The present effect, however, is that a very large proportion of the sugar of Barbados is to-day manufactured in factories turning out refiners'

crystals in place of the old and wasteful muscovado sugar, by which the prosperity of the colony has been greatly enhanced, and the situation much improved as regards the supplying of sugar during the stress of war.

It will generally be admitted that the central sugar factory established at Gunthorpes has amply fulfilled the expectations of its promoters. The effect of its successful working, coupled with full dissemination of the results of its operation, including statements of the methods employed and their cost, has reacted notably on the sugar industry of the British West Iddies. Few Government investments have been more productive of good than the £15,000 contributed to that factory scheme by the wise prevision of the then Governor of the Colony, Sir Gerald Strickland.

Other matters besides sugae have had attention on the part of the Imperial and associated Departments of Agriculture.

In connection with cacao there has been much study of the pests and diseases to which this crop is liable, and material progress has been made in unravelling the complex stories which these troubles present. These matters cannot be dealt with in detail here ; they are referred to at length in various departmental publications.

Attention, too, has been given in the experiment stations and on the estates of private owners to questions related to the planting, cultivating, and manuring of cacao trees, together with some consideration of the varieties grown. In this way information of useful character has been gathered and disseminated concerning the manurial requirements of the cacao tree, the budding and grafting of cacao, and the handling of cacao plantations generally. While much has been done, this field of work still presents many problems of interest, particularly in regard to the preparation of the cacao bean for market, and the meeting of the requirements of the manufacturers of chocolate and cocoa.

Similarly, much work has been done in connection with the lime industry. The pests and diseases affecting lime trees have been carefully studied ; the methods of cultivation and manuring of lime trees have been investigated, and also the preparation of lime products for market. In this last connexion much has been done to improve the preparation of concentrated lime juice, the principal product of the lime, which finds its way into a number of manufacturing industries, notably for the preparation of citric acid, and in dyeing and calico printing. Assistance was given in demonstrating the method of making citrate of lime which is used in the manufacture of citric acid. A comprehensive handbook has been published, giving information concerning the cultivation and treatment of lime trees and the manipulation of their products.

In recent years an experiment station devoted to the cultivation of limes and the investigation of the problems incident thereto has been established in Dominica, and already many valuable lessons have been learned from it.

In connexion with the worb of the St. Lucia Departmen of Agriculture, a factory has been established for the purchase of limes on a profit-sharing basis, and the preparation from them of

essential oil and concentrated lime juice. The object of this venture was to encourage the planting of limes in that island, and to afford a means of disposing of the fruit to those whose cultivation is too small to warrant the erection of the machinery required for its manipulation ; at the same time the facilities thus offered are of material service to the larger cultivators in the earlier stages of their enterprise, for they can dispose of the small quantities of fruit which mature in the firse few years of the growth of their trees, and thereby defer the expense of erecting machinery until they are in possession of sufficiently large crops to warrant the required outlay. This factory is equipped with steamboiling plant, the use of which had been advocated departmentally for years, but which had been adopted by large growers in only a few instances. In the operation of this factory much valuable information has been acquired, for careful account is kept of the various operations , it has been demonstrated that by concentrating lime juice by steam heat the loss of citric acid by burning can be reduced to quite low limits, whereas, when the concentration is carried on over open fires, as was formely the method commonly in vogue, the loss is frequently very large, and, in cases where the work is conducted carelessly, it may be disastrously so. As the outcome of this demonstration and the publication of the information thus made available, the introduction of steam-heated plants has become fairly general. By the use of such apparatus the quality of the product is considerably improved, so that it is capable of direct use in calico printin.

The operation of the St. Lucia Government lime-juice factory proved a great stimulus to the development of the lime industry in that colony and, incidentally, led to much greater attention being given to agricultural matters there, so that important results followed from a simple expansion of departmental activity.

Something might be said concerning the work done in connexion with crops which can hardly be regarded as staple industries, but which have local significance. For example, attention has been given to the production of maize, a matter of importance, for such maize is consumdd as corn meal in all the islands. It really constitutes one of the principal foods of the people. The necessity for producing food during war conditions, and even now, with production and shipping difficulties, has stimulated this work. Corn driers and mills for the production of meal were erected in Antigua and in St. Vincent, the granaries thuf created being operated by the agricultural departments, corn (maize) being purchased on profit-sharing lines, and meal or grain sold for local consumption. This work stimulated production, not only on the part of those who sold their corn to the granaries, but also on the part of those who grew it for use on their own plantations, for the fear of loss of the grain from its becoming mouldy, due to insufficient drying in a damp climate, deterred many from growing maize. Now, with the assistance of central drying appliances by which grain can be dried at a small charge, a sense of security results, and production is increased.

The Government granary at St. Vincent has been particularly successful and instructive. Through its operations a large

proportion of the corn and corn meal consumed in the colony is now produced locally. A further interesting step was taken at this granary during the war ; a small storehouse was built in which perishable commodities such as corn, rice, and peas were stored under conditions whereby they were kept free from insect attack. after treatment, if necessary in the grain drier. This is of considerable convenience to dealers, for great difficulties are often experienced in storing commodities of this nature. The granary at Antigua has been less successful than that at St. Vincent.

Amongst other efforts to encourage minor industries, reference may be made to what has been done with onion growing. Work was taken in hand, chiefly in Antigua, to ascertain whether onion-growing would be possible in these islands. The difficulties were investigated, and correct methods of practice were developed, so that, after some years of work ahd many interruptions and discouragements, an onion industry of moderate proportions has now been secured, mainly in Antigua. but with extension to some of the other islands. One interesting feature of this work is that the greater part of the onion crop is handled through the Onion Growers' Association, on a co-operative and profit-sharing basis. In developing matters to this point, much patient work was done by departmental officers in studying conditions of cultivation, the provision of the best type of seed, the control of pests and diseases, and the handling and marketing of the crop.

Work connected with other industries might be described, did time permit. Detailed reference may, however, be made to one industry, the establishment of which as a staple industry has been one of the marked successes of departmental work, and which illustrates very completely the difficulties and complexities which have to be met in introducing a new industry. It is not sufficient to provide the seed or planting material, and to point to a demand for the commodity in question: all the details of cultivation, seed production, control of pests and diseases, preparing and marketing the crop, and many others, have to be dealt with. These matters imply the work of a variety of individuals, each capable of dealing with that part of the work in which he possesses skill and knowledge.

The introduction of the Sea Island cotton industry, and its development to such a position that the welfare of more than one West Indian community now depends upon it, may be worth recording. When sugar-growers were at their wits' end to know what crops to cultivate in view of the losses which they were incurring over sugar production and the threatened extinction of the sugar industry, attention turned to cotton, which had been cultivated in the West Indies in former days. Some experiments in cotton cultivation which had been conducted in one or two of the departmental experiment stations attracted the notice of one planter in St. Kitts. On the strength of these experiments, he determined to make a trial of cotton-growing on a small scale. The results were promising, and they were watched with interest by the officers of the Agricultural Department. As the outcome of the preliminary trials, it was decided to attempt the cultivation on an extended scale in St Kitts and in the neighbouring island of Montserrat. The cotton grew

promisingly, but difficulties soon cropped up. It will be interesting to trace some of them as indicating what is necessary in building up a new industry.

In the following account little regard is paid to chronological sequence or to distinguishing between the localities in which the difficulties occurred: it will be understood that there was much overlapping as regards the time and manner in which events took place.

It was speedily seen that very special care would have to be taken to obtian the right kind of seed to produce the most suitable type of cotton, and to ensure the production year by year of seed of the required type. Deterioration of type was recognised in the lots of cotton first grown. In some other countries this deterioration soon let to failure of similar attempts to establish an industry. Consequently efforts were made to procure the best types of seed available, and Sir Daniel Morris, then Imperial Commissioner of Agriculture, visited the Sea Island districts of South Carolina in order to learn all that he could of the methods of cultivation and seed production followed there During this visit he procured several tons of seed of a fine type of Sea Island cotton, which were distributed throughout the cotton-growing areas of the British West Indies. Concurrently, much attention was given by departmental officers in several colonies to questions pertaining to seed production and the selection of good types. As the outcome, not only was seed deterioration arrested, but several good types of Sea Island cotton have been produced, so that the quality of the cotton grown in these islands has tended to improve instead of to deteriorate.

As a further step in this connexion, the study of plant-breeding problems in relation to cotton is being carried on in a scientific manner. This work is of very great complexity, and for its prosecution requires the services of workers highly trained in the modern science of genetics. In order that this may be done effectively, assistance has been given by the Department of Scientific and Industrial Research, and a special worker is now engaged in investigating the intricacies of Sea Island cotton-breeding. Already results of a far-reaching character have been secured, and some of the leading principles connected with the raising of the required types of cotton are being eluidated, so that this work, in combination with that of the workers in the several experiment stations, gives assurance that good types of cotton will be maintained in these islands, that desirable new types may be evolved, and also that, as the requirements of the spinners are known, it will be possible to produce the types of cotton which they desire. The importance of this will be recognized when it is stated that the Sea Island cotton is the finest cotton now grown, and that the West Indian types compare every favourably indeed with those which have been produced elsewhere. Sea Island cotton is produced in only one or two districts; practically these are confined to certain areas in Carolina, Georgia and Florida, in the United States, and the West Indian areas into which the introduction has recently been made. The invasion of the Mexican boll weevil, which has now reached almost all the areas in the Southern Untied States where Sea Island cotton has been grown, makes the cultivation

of this cotton practically impossible there. Present production, therefore, depends mainly on the West Indies, though efforts are being made to grow the crop elsewhere. These facts are of the highest significance to the British fine-spinners who use this type of cotton.

No sooner had Sea Island cotton-growing assumed moderate proportions in the West Indies, than a number of pests and diseases made their appearance. Almost any one of these would have sufficed to kill the infant industry, if means had not been found to control it. Not only are these pests and diseases new in the experience of the cultivators, but several are new to science It was necessary to study them in thorough detail, and to devise means of combating them. In all this the various officers of the agricultural departments worked energetically in conjunction with the planters.

The nature of the work may be judged to a certain extent from the following account of some of the pests and diseases which have to be dealt with.

Cottonworm (*Alabama argillacea*, Hubn.) appeared in great abundance, completely denuding the fields, if uncontrolled, thus threatening ruin to the crop. The habits of this insect were studied, together with those of the natural enemies which might be capable of holding it in check, of which there are several, and means of controlling the pest by dusting with arsenical powders were developed. The position now is well understsod, both by the officers of the agricultural departments and by the planters, encluding the peasant cotton-growers, who require, however, much supervision on the part of the departmental agricultural instructors in order to prevent the invasion of the pest and its spread to their neighbours. Several tons of arsenical powders, such as Paris green. London purple, and calcium arsenate, may be required for use in a season when this pests is prevalent.

Much alarm was caused in the early days of the industry by the appearance of a new and hitherto unrecorded pest, which attacked all parts of the cotton plant, except the roots, causing the formation of small galls, or blisters, and the distortion and stunting of the leaves and other green parts. This was shown to be due to the invasions of a microscopic mite, (*Eriophyes gossypii*, Banks.) an insect new to science, new also to agricultural experience, for which the remedial treatment was not known. The investigation of this pest involved much work, and many remedial measures were tried ; ultimately it was found that the best means of controlling it is by instituting close seasons during which no cotton plants are permitted to be in existence, all cotton bushes being destroyed prior to the date fixed for the beginning of the season, and no planting being permitted before its expiration. Regulations to this effect are enforced by law in the several islands where cotton growing is of importance.

Another pest which threatened the industry is the flower-bud maggot (*Contarinia gossypii* Felt.) This is the maggot of a minute fly, or midge, which lays its eggs in the very young flower-bud of the cotton. From the egg develops a small maggot, which causes the blossom to fall off. The attacks of this pest are sometimes so severe that the attacked fields produce practically no cotton at all. This pest, too, was entirely new to

science and to agricultural experience. It has not been found possible to devise direct remedies, and the best means of control yet found is the careful destruction of infected material and the regulation of the planting so as to avoid the later periods when the pest tends to become abundant. This pest still remains somewhat of a menace to the industry.

Red maggot (*Porricondyla gossypii*, Coquillet), the larva of a small fly, attacks the stem of the cotton plant in some localities; the cotton aphis (*Aphis gossypii*, Glover)); the cut worm, (*Prodenia spp*); various scale insects; red spider (*Tetranychus gloveri*, Banks; the Lachnopus weevil; have all, at various times caused trouble and anxiety to cotton growers, and have been the subject of study and investigation on the part of the scientific staff and the field officers of the departments.

In addition to trouble arising from insects attacking the growing plant, there are those which attack the stored seed, and these have had to be dealt with.

Many fungus diseases have proved alarming, and in some cases disastrous, to cotton growers in the West Indies. Some of these attack the leaves, as leaf rust, due to *Uredo gossypii*; leaf mildew, caused by an undetermined fungus, and angular leaf spot, due to *Pseudomonas malvacearum*. Other leaf diseases are known which are not parasitic, but which appear to be due to adverse physiological causes; among these are the curly-leaf disease, and the so-called boggerhead disease. A red leaf disease symptomatic of potash shortage is at present much in evidence in St Vincent.

Of great importance are the fungus and bacterial diseases which attack the boll—amongst these are rots caused by Phytophthora and other fungi; a serious rot caused by *Pseudomonas malvacearum*, characterized at the outset by lesions on the outer surface of the boll; but most important of all is the disease known as the internal boll disease. As this disease has given rise to some of the most interesting, complex, and successful work of the Imperial Department of Agriculture, involving the co-operation of other workers in the local departments, it may be dealt with at some little length, for it well illustrates the nature of the work which departments of agriculture are called upon to do when the introduction of new crops is under consideration, and the remarkable complications which ensue.

The internal boll disease of cotton was observed in the early days of cotton cultivation, but its real nature was not ascertained until after some ten years of work, for it presents complications which proved baffling. When the diseased bolls were examined on various occasions, it was first thought that the rotting of the lint was caused by a bacterium, further investigations led to the discovery in other instances of a fungus of a peculiar type; further research showed that at least four related species of fungus are to be met with, and in a few cases bacteria may also be involved. Seeing that no external lesions are visible, the question of the manner in which the disease, whether in its fungus or bacterial form, gains entry to the boll, presented difficulty. From the presence of internal proliferation associated with tiny puncture marks, it was suspected that the plant-sucking bug, *Dysdercus*, known locally as the cotton stainer

might be involved. After long inquiry and careful work, it was finally proved that Dysdercus does convey the infection, so that it was evident that remedial measures must include the elimination of this insect. Here at once further difficulty arose, for no parasite or natural enemy is known to attack Dysdercus to any appreciable extent; few birds will eat it; and it cannot be controlled by placing poisonous materials on the cotton bolls, for it feeds by sucking the juices from the seeds, and so avoids the poison It will readily be appreciated that this situation gave rise to much work and to no little anxiety. Finally it was agreed that the best methods of attack would be by combining starving the insect with hand-collecting. From the fact that these insects occur in enormous numbers, and breed with extraordinary rapidity, hand collecting would be of little avail unless the process of starving them tended to reduce their numbers. The adoption of the close season already mentioned was looked to to reduce their numbers, but it was soon observed that the insects were carried over in great abundance from one season to another, owing to their finding sustenance on other plants. It became necessary then to deal with the other food plants, and legislative powers were taken to enable officers of the agricultural department to enter upon anyone's land and destroy the food plants of the cotton stainer. The cotton-growers themselves, in many instances, entered actively into the campaign, and destroyed such food plants on their properties, and assisted the agricultural officers in their efforts to destroy them elsewhere. Investigation shows that two trees were principally concerned in the maintenance of the insect in the absence of the cotton plant, namely, *Thespesia populnea*, a malvaceous tree common on the beaches, known locally under the names 'John Bull' or 'Seaside Mahoe' and others, and the second the Silk-Cotton (*Eriodendron anfractuosum*). It was no easy task to destroy all these trees throughout an island, or even to reduce their numbers to insignificance, but by vigorous and well-directed activity this task was accomplished in St. Vincent and is in process of accomplishment in other places. Those who are familiar with the tropics will realise that the destruction of such huge trees as the silk cotton, long famous for its bulk and fantastic shape, presents peculiar difficulties, nor are these difficulties, nor are these difficulties lessened by the fact that these trees are often regarded by a superstitious negro peasantry as the abode of evil spirits, jumbies or duppies, who will wreak vengeance on those who destroy their haunts. Fortunately, it is also a matter of superstition that less harm is likely to happen if the cutting of the tree is done by a left-handed man. Now the Agricultural Superintendent in St. Vincent happened to be ambidextrous, so it was diplometic for him to begin the work with a few left-handed cuts, when the timorous workpeople could continue it proclaiming under their breath, 'Its no me do it; its Mr. S.' In this way the work was carried to such a successful point that the trees were destroyed, practically eradicated, but the superstitions were to some extent supported, for a falling tree killed one of the workmen, thus showing how dangerous it is to meddle with the supernatural.

So successful has been the result that the cotton stainers are very largely under control in St. Vincent, and on the belated arrival of small swarms are capable of being kept within bounds by hand-collecting. This work has altered the whole aspect of

cotton growing in St. Vincent. The prevalence of internal boll disease not long ago threatened to extinguish the cotton industry there, for in that colony difficulty is experienced in reaping an early yield, owing to the prevalence of boll rotting diseases encouraged by the heavy rains, while the later yield in drier weather was ruined by internal boll disease. From these causes the production of cotton per acre in St. Vincent fell steadily until it had reached a point when the industry ceased to be remunerative at ordinary prices for cotton. Since the adoption of the remedial measures here detailed the yield has been practically doubled. though it is still lower than is desirable, and it is hoped that the ability to combat this major evil will give such encouragement to all concerned that it will now be found possible to deal effectively with other troubles, and to bring up the yield of cotton in St. Vincent to a high figure, comparable with that attained in islands less embarrassed by disease and difficult climatic conditions.

It would be possible to extend considerably this list of matters which have required consideration at the hands of departmental officers in connexion with the establishment of the cotton industry. Something might be said about the knowledge which had to be obtained concerning the ginning of the cotton, for much of the information that had to be gained was acquired through the aid of the agricultural departments, and in some instances departmental officers had charge of ginneries and their working. Similarly, a good deal of departmental assistance has been given in the marketing of cotton, and in formulating the knowledge that has been gained in regard to the various types of cotton and their suitability for the repuirements of the spinners. Sufficient, however, has been said to show how considerable and how varied is the departmental work which has been invoked in order to establish this one industry.

The simple outline so far given of some of the work done in recent years may serve to show how different is the outlook of a modern agricultual department in the tropics from that of the botanic garden in which it had its origin, and whose functions amongst many others it still continues to discharge.

It is evident that these changes of function and outlook involve changes in the men who have charge of the several branches of these institutions. For work in the botanic gardens men were required who had botanical knowledge coupled with horticultural skill extending to some knowledge of the economic uses of the plants introduded and recommended for wider propagation. If these workers were skilled in knowledge of how to deal with these plants as crops when grown on a large scale so much the better, but the planter was supposed to take care of this aspect of the case. The process of evolution into the agricultural department, however, soon called for the help and advice of specialist workers whose knowledge in various directions went beyond that of the practical agriculturists; hence it occurred that in the evolutionary process, first chemists were called for to advise concerning soils, fertilisers, and the manipulation of plant products such as sugar, lime juic, cacao, and other products. Then it was soon found that insect pests were threatening most of the crops grown, in some cases to the extent of destroying them, so entomologists were added to the depart-

mental staffs; but this was found to be insufficient, for when insect injuries were investigated it was found that many of the troubles were due, not to insects, but to fungi and bacteria, so recourse had to be had to mycologists.

Hence we find that in most tropical agricultural departments which have envolved in the manner indicated, the scientific staff consists of a chemist, an entomologist, and a mycologist, while the botanic garden, with its associated experiment station, often grown to dimensions which overshadow the botanical aspect, is under the charge of an officer who has had training in botanical knowledge coupled with that pertaining to horticulture verging into agriculture; his assistants are usually men who can carry information regarding the recognized and approved methods of agricultural practice to cultivators, including in this work advisng as to the application of methods recently made known, either in regard to particular crops, or the remedial measures to be adopted to control the pests and diseases to which they are liable.

The members of the staff of an agricultural department so equipped must, in order to be of service to the agricultural community, get into touch with agricultural practice proper, so that there is a disposition for the workers added to the departments to endeavour, and rightly, to gain an acquaintance as complete as possible with agricultural practice; and in the final result we have tended to get agriculturists with a chemical, an emtomoligical, or a mycological point of view.

This is where matters appear to stand to-day in most tropical agricultural departments, but the process of evolution does not end here. We are now confronted in the tropics with the necessity for investigating agricultural problems of great complexity, concerning which our guides in other countries and our text-books are unable to help us. New knowledge is necessary for the solution of many of the problems on which successful progress in agriculture in the tropics depends. There is need for those who can give us further information concerning the various plants grown, and to be grown, as tropical crops; information concerning the physiology of the plants, their adaptability to their surroundings, both customary and new; information concerning the influence of climate as affecting crops, and the limitations exercised thereby, and generally as to the relation of several plants to their environment—all work of the botanist, plant physiologist, or ecologist, as yet almost unknown in relation to tropical agriculture.

Similarly, many soil problems require investigation in the light of the flood of increasing knowledge relating to soil physics, soil biology, and many cognate matters. These things call for the work of specialists of a class hitherto not considered necessary in the tropical agricultural departments.

Much more remains to be done in connexion with plant pests and diseases than the limited number of entomologists and mycologists have been able to undertake, and we may expect substantial addition to their ranks. On the scientific side concerned with investigations and the making of additions to knowledge there is room for much expansion—for many problems, some of immediate practical bearing, are calling for

solution—and it is along these lines that we may look for developments in the near future.

On what may be regarded as the more immediately utilitarian side, such as concerns the agricultural superintendents, the curators, and those having charge of matters immediately concerned with the production of crops, there has been a great expansion in outlook. This is evident when it is remembered that an Agricultural Superintendent in one of our smaller colonies is now expected, not only to maintain his botanic garden and his experiment or demonstration station in good order, so as to afford enlightenment to the agriculturists of the community, but he must be alert to recognize the appearance of disease, troubles, or deficiencies in the staple crops as well as the minor crops of his district. He is looked to provide or indicate the manner in which can be obtained the material required for planting various crops, and either himself to undertake, or to show how there can be undertaken, the best methods of maintaining the most desirable types of the crops that are cultivated locally. He is looked to, to a large extent, as the medium through which the researches and investigations of the scientific officers reach the agriculturists, and are applied in practice. He is required to assist actively in such matters of economic interest as the development of those industries which require State assistance, such as the operation of cotton ginneries, corn driers, granaries, lime-juice factories, onion buying and marketing institutions, and other agencies of a semi-commercial or fully commercial character; to give assistance in establishing such organizations as agricultural credit societies, to be active in connection with the local agricultural society, that important medium through which the agricultural department can make known its views and reseaches to the planters, and by means of which the planters in turn can make known their requirements to the department. All this and much more implies wide knowledge, common-sense, and special aptitude on the part of any man who becomes a successful Agricultural Superintendent.

Thus regarded and equipped in the manner discussed, tropical departments of agriculture are organizations of great complexity, involving in many of their aspects a high degree of specialization on the part of their workers. This gives rise to two problems—the training of the men to be engaged in the several activities of the departments, and the manner in which such departments may be organized and held together.

In regard to the first of these considerations, most of the workers in the West Indian departments have gained the greater part of their tropical training and experience in connexion with the Imperial Department of Agriculture and the several local agricultural departments, associated with it. In their several degrees the men engaged have had good sound general training in the subjects more immediately connected with the duties which they have come out to undertake, in so far as this training can be given in institutions outside the tropics. Their tropical training has been acquired in the course of the performance of their duties. Seeing that the several West Indian islands present great diversity in regard to their agriculture and in regard to the problems to which this diversity

gives rise and seeing that by their association into an organized group through the activities of the Imperial Department of Agriculture. there has been brought into close relationship a fairly large body of men of diverse trainfng, knowledge, and outlook, the Imperial Department of Agriculture has proved a good trainihg-ground, and men have gone from it and its associated departments to all parts of the tropical world, where they have successfully undertaken a great variety of duties as workers in botanical and agricultural establishments of various kinds, and as scientific investigators and advisers connected with such establishment.

The future, however, calls for something more definite in the way of training than this, for there is a demand for a greater nnmber of men than can be provided in this way, and for men whose work and duty lie beyond the confines of official agricultural departments. Trained men of many and diverse grades are required for plantation work all over the tropical world, so that there is immediate need for the establishment of a Tropica Agricultural College, whereby the present deficiencies in the way of training may be made good, and a supply of trained men be provided. The call of the tropics for developement is urgeant, but the men capable of intelligently obeying the call are relatively few in number.

A further aspect of an agricultural college is that it would provide a means of extending work in regard to research and abstract investigation. Associated in some manner, as it should be, with an agricultural department, it should help to extend the research work of the deparment, while in turn receiviffg inspiration with regard to the real needs of tropical agriculture in its practical aspects.

This brief reference to a tropical agricultural college must suffice : the subject is one which is receiving earnest attention at the moment on the part of responsible authorities, headed by the Secretary of State for the Colonies. It is a subject which will doubtless have consideration on the part of the Royal Society of Arts as one of the many institutions which take an interest in the maintenance and development of our tropical possessions, now recognized as being of such importance to our national welfare.

With regard to the second problem – namely, the manner in which the departments may be organized and held together— something may be learned from the history and working of the Imperial Department of Agriculture.

Where a number of relatively small, scattered communities occur such as exists in the West Indies, it is essential to have some centralizing or grouping organization, for it is not possible to maintain the full machinery for agricultural administration in each small community ; this function the Imperial Department well fills. It presents the advantage that, through the medium of the scientific officers maintained on its staff, it is able to undertake researches and to give advice concerning matters with which local observers and agriculturists are not fully informed, or which, as so frequently occurs, are entirely new to experience, and have to be completely investigated before advice can be given concerning them. As a centralizing organization it is able to assist in ensuring that the agricultural work in

each of the scattered communities is maintained on similarly advanced planes, and that knowledge gained by experience is rapidly passed from one to the other. Through its agency it has been possible to induce greater uniformity in connexion with matters of common interest, notably in such matters as concern the regulations regarding plant pests and diseases, and those relating to measures taken for the prevention of the introduction of these into the several islands. Through its operations much has been done to ensure continuity of agricultural policy; it is of material service in advising concerning the staffing of the several departments, and in aiding the selection of suitable officers and their transfer to advantage when vacancies occur, and in many matters of administrative detail.

An important function is the assistance it is able to afford in framing the agricultural policy of the communities, directing attention to desirable, or necessary lines of work, supervising the work when in progress, and often preventing retrogression under the influence of narrow or mistaken lines of policy, agricultural as well as administrative.

These and similar functions are capable of being exercised when advice is sought in regard to the larger colonies, and in this connexion it is felt that there is scope for extended usefulness.

It has been the purpose of these remarks to indicate in some degree the manner in which the several West Indian agricultural departments have been evolved from the simple gardens intended to foster plant introductions; it will be recognized that in this progress great complexity has arisen, rendering desirable the existence of centralizing institutions, failing which it would be difficult or impossible to maintain the progress already instituted. The impetus gained may enable the work to be maintained for a time, but the momentum would diminish, and first the smaller communities, and then the larger would fall back into a condition of isolation and stagnation in which they would be unable to maintain themselves in face of the economic struggle and competition which must inevitably soon make their pressure acutely felt once more. Closer grouping, improved means of agricultural education, and increasing agricultural research are all called for in greater degrees in the future. The work instituted by Mr. Joseph Chamberlain some twenty years ago with a view to relieving the necessities of the West Indies has borne good fruit, and its continuance should be assured by the formulation of well-thought-out plans for the future.

DISCUSSION.

The Chairman, Sir David Prain, in opening the discussion, said the Society was indebted to the author for an exceedingly luminous history of the recent progress in West Indian agriculture, while it was perhaps more indebted to him for having given on account of the stewardship of the Imperial Department over which he presided. In both those respects the paper was intensely interesting to all West Indians, past and present. With reference to the account the author had given of how it ha become necessary in certain colonies for agricultural departments to take the place of the older botanical departments, in small

colonies the question of costs came in ; it was not possible to afford two departments of the kind. One had to be considered as a luxury which must be dispensed with ; as a result the botanical departments had suffered. Only in the larger dependencies, such as India, was it possible to continue the existence of both departments. There was a considerable disadvantage in the loss of a botanical department. An agricultural department did excellent work in instructing the producer of crops, but, unfortunately, in all countries in which agricultural interests were the principal concern it was necessary for the Administrator to know something, not only about the crops, but about those natural vegetable products which were the sources of revenue of the colony or dependency which he had to administer. An agricultural department could instruct the grower, but it was not always quite so easy, and it needed a botanical department, to educate the Administrator.

Sir George R. Le Hunte, G.C.M.G., late Governor of Trinidad and Tobago, desired to bear testimony to the undiluted success of the work which had been done by the Imperial Department of Agricultural in the West Inbies. It might be summed up by saying that Kew had been brought to the islands instead of the islands goihg to Kew. He was very glad to meet Captain Hill again. He represented Kew at the West Indian Agricultural Conference in Trinidad when he (the speaker) was there. The detailed account given in the paper of the many tropical plant diseases which had to be dealt with reminded him of the remark of a friend of his that gambling on the Stock Exchange was a solid security compared to embarking on tropical agriculture. But although agriculturists had a great many troubles to face, they now had the means of circumventing and combating them, and one of the greatest helps that the tropical planter had ever possessed was the agricultural departments in the West Indies. Most of them were the children of Kew and the Board of Agriculture. Such a department existed in Trinidad and they were always delighted in that colony to welcome the Commissioner or any of the officers of the Imperial Department of Agriculture. He remembered that when the Department was started he was in Dominica, and an arid-looking part of a sugar estate was then purchased, and had now been turned into one of the most beautiful tropical gardens in the world. He recollected a planter friend of his in Dominica sending a box of leaves from a lime tree to the Agricultural Bureau in America, asking for advice in the treatment of a disease which affected the leaves, and he subsequently received a reply requesting that in future the leaves from separate trees should be sent in separate parcels, because thirteen different diseases had been discovered in the leaves which he had sent. As a matter of fact, they came from only one tree. When a planter was faced with such difficulties, it was necessary for him to turn to some doctor to help him, and he now possessed the advantage of being able to consult the officers of the Imperial Department of Agriculture. Reference was made in the paper to the establishment of an agricultural college in the West Indies, and he trusted that if a discussion took place at any future time before the Society on that question he would be invited to attend, because he foresaw a rather big war between the interested parties, and he would be very anxious to see which way the battle went.

Mr. A. Howard, C.I.E., M.A., F.L.S., Imperial Economic Botanist to the Government of India, said he desired in the first place to discuss the question of the best method of procedure on the part of scientists who went out to the tropics to advance agriculture. It had been found in India that a very successful method was for the scientists to take up the subject, so that they combined in one person a practical experience of agriculture and of a particular science. There were now a large number of experimental stations in India, in which all the details were managed by the scientific men in addition to carrying out their own particular work. A large portion of the paper was taken up with references to diseases of various various crops, and in that respect a good deal of new ground had been broken in India in the last two or three years. The orthodox view was that the diseases were caused either by insects or by fungi, and that the best method of attack was to study the life history of the insects or fungi and to endeavour to find some remedial method of control. The subject was now being looked at in India from a somewhat different point of view. It had been found that insects and fungi, although important factors in the case, were not everything, and results in the treatment of disease were now being obtained by considering the physiological activities of plants, particularly the distribution of the root system and the effect of the physical texture of the soil. During the last two or three years it had been found possible to grow cotton in parts of India with a rainfall of 70 inches absolutely free from disease, a thing that was considered impossible in days gone by. That had been bought about by selecting soils in which the physical texture was practically perfect, and in which healthy root development was possible ; and a large number of similar results were now being obtained at other centres. The treatment of disease now appeared to be very much more hopetul. It was not a question so much of spraying as of improving the physical texture of the soil, and selecting types of plants with root systems which were specially adapted to particular classes of soil.

Mr. C. Sandbach Parker, C.B.E., said that as one long interested in sugar-growing in British Guiana he desired to add his personal testimony to the value of the Imperial Department of Agriculture in the West Indies. British Guiana, like Trinidad, had its own department, and in addition there were individuals who were doing pioneer work ; in fact, British Guiana in that respect was rather more modern than some of the West Indies, but he thought there was not the slightest doubt that the more the Imperial epartment of Agriculture was used the more valuble it would be to tropical agriculture, not only in the West Indies, but in British Guiana and other tropical countries. It was only necessary to refer to the wonderful statistics which were compiled by the Department of Agriculture of America and her colonies in connexion with the growth of sugar to find out what could be done by the co-ordination and extension of their efforts in that direction in the West Indies and British Guiana. Unfortunately,during many years past the interests of the West Indies were left very much to the West Indians themselves, except for the help of Mr. Chamberlain, but changed ideas were now apparent in the Imperial Government, and there was a desire to develop the agricultural industries of all the tropical possession

of the Empire. He hoped that had come to stay. and if it did so there was an era of prosperity in front of the agricultural industries of the British possessions in the tropics such as they had never experienced before.

MR. A. ABBOTT said that the Department of Scientific and Industrial Research, with which he was connected, was engaged in the task of establishing a number of research associations. Each of the associations consisted of a group of British manufacturers who, feeling that they had common interests, had embarked on a scheme of co-operative research. About nineteen of those associations had so far been approved, of which six or eight were at work. It became obvious at a very early stage that if those associations existing in England began their work of research on the raw materials as they entered these shores, they would be too late; it was necessary to make an early start, and to carry on research as to the method of production of the raw materials. It was evident that it was impossible to improve the quantity of mineral productions very largely—at any rate, it could not be improved indefinitely; the number of animal products was not large, but the number of vegetable products grown in tropical countries filled an extremely long list, including timber, flax, cotton, jute, cacao, rubber, oils, seeds, spices, drugs, and certain dyes; and that pointed to the necessity of carrying on research on a large scale. He did not know the exact means that should be devised for the purpose, but it was necessary that they should be considered. Looking at it from the point of view of the West Indies, there were several directions in which help could be accorded. First of all, it was possible to communicate to the tropical department abroad the results of research carried on in this country in pure science at the universities. Secondly, it was very desirable that the producer abroad should be in very close contact with the user or the manufacturer on this side. That was one of the factors which had not been developed as much as it might have been in the past. The user in this country ought to be able to tell the producer just what he wanted, and why he wanted it, and the producer in the tropical country must have some knowledge of what the user in this country really needed. Thirdly, tropical countries must depend on this country in the main for their supply of technical men. Until quite recently, if a manufacturer wished to have a scientific man in his work, he selected a chemist as being the one scientific man who could help him. It was just beginning to be recognized that the physicist as well as the chemist could do extraordinarily useful work in industry. It had scarcely been recognized in this country at any rate, that the botanist and the entomologist had a very wide industrial field for their work; but it was quite impossible for the country to secure an adequate supply of men of that type unless it could be shown that a career awaited them in industry. As soon as the possibility of a career was obvious to young men, they would follow their bent, and take up that particular line of work.

Mr. G. MOODY STUART said the paper contained a record of twenty-one years unobtrusive work, which was hardly known except to those who were personally connected with it. As he happened to be in that position, he desired to take the opportunity of saying that he firmly believed the Agricultural

Department had been of untold value to the West Indies. The Sea Island cotton industry was not only made, but saved by the Agricultural Department in the West Indies, and many estates and several islands had been brought out of very uncomfortable uphill conditions into a position of comfortable well-being by the development which han taken place, a development entirely due to the work of the Department. Not a part'cal of what had been done in sugar development in Antigua would have been done except for the Department. The factory there had now completed fifteen years' work, and during that time it had saved sugar to the value of £130,000 which would otherwise have been wasted. That was not a bad single item to the credit of the Department The greater part of that money had gone to the planters, and through them a fair portion had filtered to the estate managers, overseers, and labourers. The author had referred to the necessity of the Department being maintained from Imperial funds, because that had been the main element of its success in the past. Personally he strongly supported the suggestion, because he felt sure that if a change were made it would be a very dangerous thing for the Department. It might be said that the West Indies ought to be able to bear their own burdens, but as a matter of fact they were bearing them to the full now. The sum of £130,000 had been given as a grant-in-aid, in addition to which the Mother Country had also borne the cost of the headquarters, but she had received much more than that back again in excess profits and income tax, which would never have been paid but for the work of the Department. A large proportion of the estates and many of the factories were owned in England, and on the profits that were made the Treasury received income tax, so that the Imperial Treasury would be looking only at one side of the account if they looked at the expenditure only. The success of the Department was due to the chemists and the men who had come from Kew, but he ventured to suggest that when the next vacancy occured a practical agriculturist with scientific knowledge should be appointed, one well acquainted with practical farming, drainage, and manures The chemists had trusted to the planters themselves being well up in the best methods of agriculture, but as a matter of fact they were only employing methods which were known to their forefathers. Agriculture had taken such big strides in recent years that he was sure that if a man who was thoroughly well up in practical farming was appointed, it would be to the benefit of the colonies. He desired to refer, in conclusion, to the spirit in which the Department had been run from first to last. It was not a typical Government Department. Usually in approaching a Government Department one felt that one was going to an authority which might or might not condescend to be interested in one's case; but in going to the Agricultural Department one always felt that one was asking for professional advice in the same way that a client went to a lawyer or a patient to a doctor, and that one was given the advice as willingly and readily as any professional man gave advice to his client.

Dr. Louis W. Sambon said that, having had the privilege and pleasure of visiting the Lesser Antilles in the instructive company of Sir Francis Watts, he eagerly seized the opportunity of expressing his high regard for the writer of the paper, and his

admiration for the work he had carried out in the West Indies. While travelling with Sir Francis, who was on a tour of inspection, he could not help wishing that the medical and sanitary work were conducted on lines such as were being followed by the Imperial Department of Agriculture. As a student of ecology in a different field, he desired to emphasise the importance of a college such as had been outlined by the author, because no doubt the teaching of the principles of ecology would enable them to obtain men capable of raising good crops and of controlling the pests and diseases of plants. The ancients had achieved wonders in agriculture. Had time permitted he would have liked to remind them of the terraced agriculture of the aneient Mexicans, of the hanging gardens of Babylon, of the Roman transportable forcing houses, of the controlling of crop-pests by their natural enemies. An Assyrian clay cylinder, 2,500 years old, in the British Museum, handed us down Sennacherib's boast that cotton-trees throve better in his gardens on the Euphrates than in their native land. At that time, whilst Hindu, Hellenic, and Egyptian girls danced in tranparant muslins—true 'webs of woven wind,' as they were called in Sanskrit literature—the ancient Peruvians swaddled their dead in cotton bands. Moderns should at least equal, if not surpass, their endeavours, and thus be worthy followers of the ancients, whose inheritance they were so fully enjoying.

Dr. C. A. Barber, C.I.E., F.L.S., said that he had the greatest possible sympathy with the suggested agricultural college, because he felt that tropical agriculture was entering upon a new intensive phase which was not only directly, but indirectly, caused by the late war. There was a vast need for raw products, which were being produced in immense quantities, but nevertheless they could not be obtained in manufacturing countries. As a result there was an increasing tendency to deal with those raw products on the spot, an increase in the number of the factories in the tropics thereby being brought about. A large increase was taking place in the departments of agriculture all over the tropical world, and many new men were required from this country to carry on that work and extend it. It was necessary with regard to diseases to study the actual growth of plants more carefully, and not to be content with simply naming the diseases, the fungus, or the pest, without attempting to ascertain why it was caused, and without endeavouring to provide a remedy for it. He very much doubted whether a single agricultural college would be sufficient for the West Indies. In India there were a series of regular agricultural colleges, but none in the colonies. They were needed in the West Indies, and soon would be in West Africa, the Transvaal and Natal, Uganda and British East Africa, Mauritius, Ceylon, Queenland, and Oceania. If men for those colleges were to be supplied, it was necessary to do more work in England, and in that respect he did not think the present method of obtaining men for the tropical agricultural departments was likely to succeed, unless some scheme of co-ordination between the new agricultural college and those in this country was put into force—some scheme of preliminary training to bridge over the gulf between the knowledge of agriculture in temperate climates and in the tropics. From long experience of the tropics, he found that it look sometime two or three years

before a man who had been trained in an English college was in a position to adapt himself to his surroundings, and to be of much use.

SIR EVERARD IM THURN, K.C.M.G., K.B.E., C.B., in proposing a hearty vote of thanks to Sir Francis Watts for writting the paper, and to Captain Hill for reading it, and at the same time informally thanking Sir David Prain for his kindness in presiding over the meeting, said that he saw, perhaps more than anybody else present, the beginning of the operations which Sir Francis Watts had described. Forty years ago he was resident in British Guiana, before the Botanical Gardens there existed. He saw the extraordinarily good work which the first Curator, the late Mr. G. S. Jenman, did, and the subsequent work performed by his successor, Dr. Harrisson. The contrast between the botanical garden work and the agricultural side of the work had been in his mind during the reading of the paper. He quite saw the necessity for practical purposes that the agricultural tendency should take the lead, but at the same time he could not help feeling a certain amount of regret at the dropping of the botanical garden side of the question. Speaking from his own long experience, he was perfectly certain that the care which was given to the introduction of minor products, and not merely the main products, be they sugar-cane or coconuts, should be a very important feature of any agricultural department; and though attention must be paid to commercial products, he hoped the smaller and minor industries would not be overlooked. He did not mean for a moment to suggest that they were purposely neglected, but there was a strong suspicion that they were being allowed to drop out. A good deal had been said in reference to the advantages of a large Agricultural Department formed by the union of various smaller institutions, and he would like to see that principle extended still further. In any Imperial Agricultural Department, the outlying parts of the world, which had practically been untouched from the scientific agricultural point of view, had not yet been taken much into consideration. In that connexion he desired to utter a note of warning, that the conditions of agriculture in the Pacific and in the West Indies were so extraordinarily different, that when men were being trained for agriculture in the West Indies it was necessary to bear in mind that, if they were transferred by any chance to Oceania, the conditions there would be very different. For instance, the conditions under which sugar-cane was grown in Fiji and in the West Indies and British Guiana were extraordinarily different.

SIR LOUIS DANE, G.C.I.E., C.S.I., in seconding the motion, said that he was very glad to find that an attempt was being made to overcome the difficulties that at present existed in regard to the importation of Indian labour into the West Indies. The West Indies depended to a very large extent upon India for their labour, and he hoped therefore that the present difficulties would be surmounted. He thought, however, it would be wise for the administrators of the West Indies to realise that it would be quite impossible for them to secure Indian labour in the future upon the old terms. He had no doubt whatever that Indian labourers would be forthcoming, but it would be necessary for the

West Indies to take them absolutely as free labourers, and if they did so, plenty of excellent labour would be available. Speaking as an Indian Administrator, he was able to say that he had never heard of any trouble at all with the returned immigrants from the West Indies or British Guiana, who were peaceful and prosperous men, although trouble had been experienced when Indians had returned from other parts of the world. He agreed with Sir Everard im Thurn that it was absolutely necessary to have not only an agricultural department and colleges, but also a botanical department and botanical gardens. The two really did not serve the same purpose. The first dealt with commercial agriculture; the second dealt with the introduction of new specimens which were to a great extent entirely beyond the scope of the economic botanists employed in the Agriccultural Department. The West Indies, as a field for agriculture, were practically a new one, but in India the circumstances were entirely different. India possessed the accumulated experience of centuries of agriculture, which was often crystallized into the very wise saws of the peasantry, which embodied great truths. The agricultural experts who went out to India from this country had at first a tendency to regard the natives as absolutely wanting in all knowledge of correct agriculture, There never was a greater mistake. Every year it was being found that Indian practice was based upon sound agricultural principles, although the people who practised them did not know the why and wherefore for them. He was glad to say the agricultural experts were beginning to finn that it was necessary to do what was suggested in the paper, namely, study the local conditions and associate themselves very elosely with local agriculturists of experience, and most happy results were hereby being produced. He could not help thinking that if there was a closer union between the Imperial Agricultural Departmnt in the West Indies and the Agriculural Department in India they would be able to benefit each other very largely. A great many of the difficulties, especially those affecting cotton and sugar-cane, that were experienced in the West Indies also obtained in India; In fact, the same problems cropped up in all the various dependencies, and it was therefore essential that there should be free communication between them, and also a certain amount of personal visitation.

The resolution of thanks was put and carried unanimously.

Captain Hill, after acknowledging on behalf of Sir Francis Watts and himself the vote of thanks, said that it was only possible for him in the short time at his disposal to refer very briefly to the remarks made by Mr. Howard. The Mycologist of the Imperial Department of Agriculture, when visiting Trinidad, found that the trouble experienced by the planters with regard to the frog hopper on the sugar-cane was not so much linked up with insects or fungi as with the physiological conditions under which the plants were growing and by taking steps to remedy the deficiencies in the cultivation the pests had been largely brought under control.

Sir Charles Lucas K.C.B., K.C.M.G., in expressing regret at his inability to attend the meeting, writes: "I should have been glad to have been there to bear witness to the Imperial Department of Agriculture for the West Indies, to the splendid

support given to it by the Directors of Kew Gardens, from which it gained Sir Daniel Morris, and to the very able services of the writer of the paper, Sir Francis Watts. It is not too much to say that the present regeneration of the West Indies from the decay into which they had fallen towards the end of the last century has been largely due to the work of the Department of Agriculture.'

SIR DANIEL MORRIS, K.C.M.G., D.Sc., F.L.S., who was also prevented from being present, to whom an advance copy of the paper was sent, writes: 'It contains a remarkably full and careful account of the evolution of agricultural efforts under the fostering care of the Imperial Department of Agriculture, and brings out very forcibly the value of scientific research in promoting the welfare of our tropical possessions. It is quite in keeping with the traditions of the Royal Society of Arts that this paper should be read under its auspices, as more than 150 years ago it presented its gold medal to Dr. Young, then head of the Batanic Garden at St. Vincent, in recognition of the flourishing state of that institution. A great deal has been accomplished in the West Indies since those days. Among some of the results of enlightenment in regard to agricultural matters, it has been shown that the public revenue of the colonies before the war had increased from two and a half million sterling to nearly four million; while the total trade had increased in value from seventeen million to nearly twenty-seven million sterling. In the case of the comparatively new cotten industry, which owes its existence so largely to the efforts of the Imperial Department of Agriculture, the exports in recent years have reached a total value of nearly two million sterling. Sir Francis Watts has rightly drawn attention to the fact that while the Imperial Department of Agriculture has continuously trained a large staff for experimental work in the West Indies, it has also turned out capable men, of university standing, who now occupy responsible positions in other portions of the tropics. Further, it has been successful in winning wide appreciation of improved methods of cultivation and of the value of science among members of the planting community, with the result that the provision for the maintenance of well-equipped staffs, laboratories, and botanic and experiment stations, voted by the local legislatures, has increased from £14,000 to more than £60,000 per annum. Having been so closely interested and taken so active a part in the development of the West Indian Colonies for a period of nearly forty years, I may be permitted to place on record that I am fully convinced of the necessity of the continuance of the valuable work that is being done by the Imperial Department of Agriculture, and I hope that the proposal to established a central agricultural college for training apable men to assist in the further development of the West Indies will meet with the success it deserves. Sir Francis Watts has very modestly said very litt'e of his own share in the great work that has been accomplished in the West Indies. He was my most valued colleague for many years in the work of the Imperial Department of Agriculture, and the great success of his efforts in connexion with the establishment of central sugar factories at Antigua and St. Kitts, and indirectly also at Jamaica and Barbados, will always be most closely and gratefully associated with his name'

THE ANTIGUA CENTRAL SUGAR FACTORY (GUNTHORPES).

BY SIR FRANCIS WATTS, K.C.M.G., D.Sc., F.I.C.,

Imperial Commissioner of Agriculture for the West Indies.

Now that by the reaping of the crop of 1919 the Antigua Central Sugar Factory at Gunthorpes has completed the terms of its original contracts, it may be interesting to review the position, and to place on record an account of its work covering the whole period.

The following account of the general terms under which this factory was planned and operated is reproduced from a former account given in this Journal.*

'The Antigua Central Sugar Factory was planned in 1903, and reaped its first crop in 1905. It had its origin in a series of agreements between a group of owners of sugar estates and a company formed in London. Under these the company agreed to erect and work a sugar factory capable of making not less than 3,000 tons of sugar in 100 working days, and the estates' proprietors agreed to supply canes from stated areas for a period of fifteen years. They were to receive as a first payment for their canes the value of 4½ lb. of 96° sugar for every 100 lb. of canes, and at the end of each season they were to receive a further payment resulting from the division between the cane suppliers of one-half of the profits of the factory, after proper charges had been made for working expenses, interest, and sinking fund. Should the price of sugar be such that the first payment on the 4½ lb. basis failed to reach 10s. per ton of canes, then the first payment was to be made up to that sum at the close of the season before any division of profits.

'The sinking fund was planned so as to redeem the capital in a period of fifteen years. As soon as this is effected there are to be issued to the contracting estates proprietors shares in the factory equal in number to the original shares in the company, so that when this happens, the contracting proprietors come into possession of shares equal to half the factory.

'To aid this scheme, the Government, out of the residue of Imperial Grant-in-aid of the Sugar Industry, gave a sum of £15,000; this was given free of interest, and appears in the accounts of the company as giving rise to the B shares and B debentures. The sum, which is in the nature of a free grant, is regarded as a Government lien on the factory, which is diminished by the amortization, without payment, of £1,000 in each year so long as the factory properly fulfils its contracts.'

The fifteen years of the contract have expired. During this time the company have fulfilled their obligations, the debentures of the company have been redeemed, and the B shares, held in trust by the Government on behalf of the original contracting

* *W. I. Bulletin*, XV., p. 47. 'Review of Ten Years' Work of the Antigua Sugar Factory, Gunthorpes.'
See also *W. I. B.*, VI., p. 60,, and IX., p 79.

proprietors, have been distributed to those proprietors, so that a definite point in the factory's history has been reached; it now enters upon new conditions, and is free from further Government intervention.

The financial position at the close of the fifteen-year period of the original contracts is shown in Table I.

TABLE I.

Year.	Cost of factory.			Debenture interest.			Interest other than debenture.			Loss on exchange.			Profits paid to shareholders.		
	£	s.	d.	£	s.	d.	£	s.	d	£	s.	d.	£	s.	d.
1905	45,358	14	9	1,434	14	6	...			...			1,942	10	10
1906	45,358	14	9	1,250	0	0	83	1	1	59	4	3	...		
1907	45,358	14	9	1,250	0	0	...			121	12	9	3,172	15	4
1908	55,360	6	0	1,238	16	8	238	19	8	180	12	3	7,081	11	2
1909	59,371	4	11	998	19	3	666	5	7	149	1	3	4,133	7	8
1910	59,769	3	8	930	19	9	827	6	3	180	16	8	7,231	7	7
1911	89,260	5	0	1,736	1	5	938	1	3	389	12	4	106	7	8
1912	93,222	3	7	1,843	12	6	797	8	10	298	10	10	7,210	7	5
1913	99,438	9	11	1,531	1	4	999	15	5	483	1	8	1,523	5	6
1914	102,961	4	5	1,447	2	11	1,461	19	0	496	12	8	1,711	15	11
1915	102,961	4	5	1,240	16	9	1,247	12	9				11,072	11	0
1916	102,961	4	5	869	16	4	2,347	1	9				23,069	1	2
1917	102,961	4	5	672	18	1	984	2	10				21,541	1	5
1918	102,961	4	5	445	8	9	1,110	1	6				16,388	19	5
1919	103,229	14	5	195	15	8	4,556	1	7				20,745	9	6
				17,086	3	5	18,617	2	2				126,930	11	7

It will be seen that the cost of the factory has been substantially increased from time to time. The first material increase took place in 1908; this was due to the addition of a Krajewski crusher to the original six-roller mill together with some addi-

tions to the railway. A further notable increase took place in 1911 in order to permit of additions to the milling plant, whereby the mills were converted into a 14-roller train; there were also substantial additions to the general plant and to the railway. In this manner the capital invested was brought up to £102,961, increased in 1919 to £103,229, at which figure it stood at the conclusion of the original contracts.

These substantial additions to capital expenditure were made concurrently with an extension of the company's contracts with planters supplying canes on a profit-sharing basis: a second group of contracting cane suppliers was established, who received payment for their canes on the basis of 5 lb. of sugar for every 100 lb of cane (the original contracting proprietors, it will be remembered, received 4½ lb.) together with their proportion of the half-profits arising from the year's working of the factory.

A simple method of calculation was resorted to in order to ascertain the share of profits due to the new contracting proprietors, as distinguished from that due to the original contracting proprietors. The total cost of working for the season, including all charges for interest and sinking fund, was determined each year; this was deducted from the gross returns arising from sales of produce, the difference being taken as the 'profit' on the year's working; this, divided by the total quantity of canes dealt with gave the 'profit' per ton of cane. By the terms of the contracts one-half of this went to the cane suppliers, and the other half to the factory; the new contracting proprietors were then paid bonus additions at this rate on the cane supplied by them.

This method of calculation gave rise to a sum arising from the 'profit' accruing to the factory as the result of dealing with the canes of the new contracting proprietors, as well as those of the original contracting proprietors: these latter had a claim on these profits as part of the profits of the factory, of which they were entitled to one-half. In order to adjust this, the final profits of the factory were taken after the deduction of the amounts paid by way of bonuses to the new contracting proprietors, and this was divided into equal moieties, one of which went to the factory as 'profit' for the season, and the other was divided amongst the original contracting proprietors in proportion to the weight of canes supplied by each. In this way the original contracting proprietors received bonus additions to their payments for canes, which made the total payment per ton of canes supplied by them higher than that made to the new contracting proprietors, notwithstanding the fact that the new contracting proprietors got a higher first payment than the original contracting proprietors. In one season, however, 1911, the new contracting proprietors obtained a higher total rate than their confreres.

Special financial arrangements were made whereby new debentures were raised bearing interest at 5 per cent. in order to meet the additional outlay, and a sinking fund was created at a rate calculated to redeem these new debentures simultaneously with the original A debentures.

All the debentures were paid off during 1919, the year in which the original contracts came to an end, the expenditure having been £103,229 14*s*. 5*d*., of which £15,000 was provided

by the Government grant, and the sum of £88,229 14*s.* 5*d.* has been paid off from the earnings of the undertaking. The factory, therefore, closes the period of its original contracts with all its debentures and loans paid off, and stands possessed of a modern plant, buildings, and railways, which may now be taken to be worth some £200,000. Shares representing one-half of this now pass into the hands of the original contracting proprietors in proportion to the weight of canes supplied by each during this period.

It will be interesting to see how the original contracting proprietors have fared. During the fifteen-year period they have supplied 350,126 tons of canes, and have received by way of first payment, the sum of £226,610, an average of 12*s.* 11*d.* per ton of canes. The sum of £126,930 11*s.* 7*d.* has been paid to them as their share of the profits of the factory during this period; this is equivalent to 11*s.* per ton of canes supplied. Furthermore they have now received shares representing one-half of the factory: if the factory is valued at £200,000, [illegible] 5*s.* 7*d.* per ton [illegible] d contracting [illegible] per ton, plus [illegible] 7*d.* per ton. [illegible] who were also [illegible] n their deben- [illegible] at the rate of [illegible] 6,930 11*s.* 7*d.* [illegible] he period. It [illegible] that these profits have been subject to Imperial Income Tax and Excess Profits Tax, and have thus been subject to heavy deductions. Information is not yet available as to the total amount thus paid, but it has been very considerable.

The accompanying pages 137—140 are substituted for similar pages incorrectly printed and issued in W.I.B. Vol. XVIII., No. 3.

The financial side of the factory itself may now be examined. As already stated, the original expenditure on the factory was £45,358 14*s.* 9*d.*; this was represented by 12,500 A shares. An equal number of B shares represented the interest in the concern of the original contracting proprietors who supplied the canes. The expenditure on the factory and its railways was subsequently increased up to £103,229 14*s.* 5*d.*

While the amount charged to capital account as the cost of the factory and its railways is £103,229 14*s.* 5*d.*, the cost of repairs and maintenance has been £97,530 15*s.* 10*d.* in respect of the factory, and £38,814 7*s.* 10*d* as regards the railway, exclusive of fuel in each case, a total of £136,345 3*s.* 8*d.*, equivalent to £1 7*s.* 3*d.* per ton of sugar made. If to this is added the sum charged to capital account, the factory has cost, to equip and maintain in its present state of efficiency, £239,571 18*s.* 1*d.* It is probable that some amounts charged to repairs and maintenance might in some circumstances have been charged to capital account, still the figures indicate that in the case of a modern and expanding sugar factory, very considerable expenditure must be allowed for, in order to meet charges for repairs and maintenance. It is suggested by some authorities that an amount equivalent to £1 per ton of sugar made should be allowed for this purpose, and this may be exceeded while machinery remains at its present high cost. The sum so expended on the Antigua factory is considerably in excess of this amount.

The financing of the factory has been managed very efficiently, and at low cost: the total amount spent on debenture interest was £17,086 3*s.* 5*d.*, and on other interest on loans, and loss on exchange, £18,617 2*s.* 2*d.*, an aggregate expenditure of £35,703 5*s.* 7*d.*, equivalent to 7*s.* 1¾*d.* per ton of sugar made. In planning other factories under present conditions, more than double that amount might reasonably be allowed.

The various financial statements plainly indicate the effect of the war upon the sugar industry; while the cost of machinery and the cost of sugar production have greatly increased, the price of sugar has increased in still greater proportion, so that factories are placed in a very favourable financial position. Not only is this the case during the period ending with the year 1919, but this position has become greatly accentuated during 1920. It is to be observed, however, that the Antigua factory was in a sound financial position before the war; it was meeting its liabilities in the manner originally planned, and was rapidly extending its operations. The effect of the changed condition due to the war was undoubtedly, to give rise to a great increase in the factory's profits, and afforded enhanced stability; but it is to be remembered that the shareholders derived comparatively little financial benefit from these increased profits, owing to the fact that the company being registered in England, the profits of the factory were subject to Imperial Income Tax and to Excess Profits Duty.

The actual position of affairs at the time when the original contracts were completed is shown by the company's financial balance sheet on September 30, 1919, which is here reproduced.

Balance Sheet, September 30, 1919.

ASSETS.

				£	s.	d.	£	s.	d.
By Cash :—									
Antigua	...	...	...	275	0	3			
London	..	...	...	36,731	14	9			
							37,006	15	0
By Sundry Debtors :—							3,457	9	11
By Investment held on account of Staff Retirement Bonus £2,000 5% National War Bonds @ Cost	...	...					2,000	0	0
By Stocks of Sugar and Molasses	...						10,640	17	1
By Stores and Spare Parts	...						38,953,	19	4
By Factory and Railways :—									
Original Capital Expenditure				45,358	14	9			
Additions :—									
To 30th Sep. 1918			57,602 9 8						
,, Since			268 10 0	57,870	19	8	103,229	14	5
							£195,288	15	9

LIABILITIES.

		£	s.	d.	£	s.	d.
To Creditors:—							
Sundry		4,934	4	5			
Planters		45,258	3	6			
To 'A' Shareholders:—					50,192	7	11
As per last account		30,081	17	9			
Less Dividend		6,250	0	0			
		23,831	17	9			
Excess Profits Duty	£10,028 0 0						
Less amount recovered	7,518 10 0						
	2,509 10 0						
Income Tax	2,532 16 0	5,042	6	0			
		18,789	11	9			
Add Interest at 5% on Balances		1,081	12	2			
		19,871	3	11			
Profit for year, subject to Excess Profits Duty and Income Tax		20,745	9	6	40,616	13	5
To Share Capital:—							
12,500 'A' shares of 1s. each, fully paid		625	0	0			
12,500 'B' shares of 1s. each, fully paid		625	0	0	1,250	0	0
To Amortisations:—							
'A' Debentures paid off		25,000	0	0			
'B' " " "		15,000	0	0			
'C' " " "		20,000	0	0			
Reserve Fund		3,000	0	0			
Sinking Fund for additions		40,229	14	5	103,229	14	5
					£195,288	15	9

T. DU BUISSON
GEO. MOODY STUART } Directors.

GEO. H. BILLINGHURST
A. D. CRICHTON } Joint Secretaries

Attention may now be turned to the working of the factory. From Table II it is seen that during the fifteen years 928,613 tons of canes were dealt with, and 99,995 tons of sugar produced: this is at the rate of 1 ton of sugar from 9·289 tons of cane; or sugar produced at the rate of 10·77 per cent. of the weight of the cane. The sugar made was ordinary 96° refiners' crystals.

TABLE II.

Year.	Total quantity of canes crushed, tons.	Total quantity of sugar made, tons.	Tons of cane to one ton of sugar.	Commercial sugar 96° made per 100 of cane.	Cost of manufacture in terms of sugar per 100 of cane.	Difference between P.C. sugar on cane & cost of manufacture in terms of sugar per 100 of cane.	Cost of manufacture per ton of sugar.			Price of sugar per ton.		
							£	s	d.	£	s.	d.
1905	15,681	1,634	9·70	10·31	2·52	7 79	3	2	6	12	15	5
1906	24,676	2,319	10·51	9·52	3·70	5·82	3	3	11	8	4	8
1907	40,782	4,231	9·64	10·37	2·87	7·47	2	14	6	9	16	0
1908	43,060	4,696	9·17	10·90	2·69	8·11	2	18	2	11	15	0
1909	37,284	3,995	9·33	10·72	3·31	7 41	3	4	1	10	7	5
1910	48,319	5,390	8·96	11·16	2·91	8·25	3	6	10½	12	16	8
1911	55,117	5,472	10·07	9·93	2·99	6·94	3	14	8½	10	11	5
1912	59,371	6,239	9·51	10·51	2 90	7·61	3	13	1	13	5	3
1913	70,348	7,337	9·58	10·43	3·60	6·83	3	5	1½	9	8	7
1914	83,030	9,131	9·09	11·00	3·83	7·17	3	3	2½	9	1	6
1915	81,520	8,390	9·72	10·29	2·32	7·97	3	13	10½	16	7	9
1916	112,356	12,371	9·08	11·01	1·99	9·02	3	4	1¼	17	13	8
1917	102,601	11,705	8·76	11·42	2·96	8·46	4	19	5	19	3	5
1918	64,282	7,316	8·79	11·39	3·37	8·02	6	0	7½	20	8	0
1919	90,186	9,739	9·26	10·80	2·77	8 03	5	11	5	24	14	1
	928,613	99,995	9·289	10·77								

The table shows the price which the sugar realized locally each year, and the cost of manufacture per ton. From this latter figure has been calculated the cost of manufacture in terms

of sugar per 100 of cane, so as to show in these terms what amount of sugar the factory recovers after deducting the amount equivalent to the cost of manufacture. This calculation is important, seeing that the canes were purchased from the original contracting proprietors on the basis of the value of 4½ lb. of sugar per 100 lb. of cane, and from the new contracting proprietors at 5 lb. The figure varies from year to year, being influenced by the amount of sugar in the canes, the efficiency of the work of the factory, and by the price of sugar. This latter factor is of great importance, for, obviously, when the value of sugar is high, it requires but little of that commodity to meet the cost of manufacture.

After deducting the cost of manufacture, the figure expressed in terms of sugar ranged from 5·82 per 100 lb. of cane in 1906 to 9·02 in 1916. In the former year it required 3·70 lb. of sugar to meet the cost of manufacturing the sugar, 9·52 lb., made from 100 lb. of cane; whereas in the latter year it required only the value of 1·99 lb. of sugar to meet the cost of manufacturing the 11·01 lb. similarly made.

These figures are of interest in connexion with those factories which purchase their canes at a price based on the value of a given percentage of sugar. Reference to Table V will show the amounts paid in these terms to the cane suppliers of the Antigua factory during the whole period under review.

In this connexion, reference may be made to the actual cost, in terms of money, of the manufacture of a ton of sugar; this is shown in Table II, and an analysis of the expenditure is given in Tables III and IV.

Table III.

Cost of Manufacture.

Year.	FACTORY. Expenditure.			FACTORY. Per ton sugar.			RAILWAY. Expenditure.			RAILWAY. Per ton sugar			ADMINISTRATION CHARGES. Expenditure.			ADMINISTRATION CHARGES. Per ton sugar.		
	£	s	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d	£	s.	d.
1905	4,085	11	2	2	10	0	367	9	3	4	6		664	3	9	8	0	
1906	5,669	12	3	2	8	3	1,289	4	11	10	11		554	19	2	4	9	
1907	8,909	0	1	2	2	1	2,028	19	0	9	7		602	3	0	2	10	
1908	10,105	12	5	2	3	5	2,733	1	6	11	7		750	6	7	3	2	
1909	10,336	9	2	2	11	9	1,804	7	4	9	0½		655	6	8	3	3½	
1910	14 047	18	8	2	12	1½	2,840	5	4	10	6½		1,132	18	10	4	2½	
1911	17,117	6	11	3	2	6¾	2,016	3	9	7	4½		1,189	3	6	4	4½	
1912	17,116	4	9	2	14	10	4,664	11	0	14	11½		1,032	5	8	3	3½	
1913	19,221	2	4	2	12	4¾	3,474	6	1	9	5½		1,207	11	1	3	3½	
1914	23,390	14	6	2	11	2¾	4,206	12	6	9	2½		1,268	0	5	2	9¼	
1915	24,835	1	1	2	19	2½	4,737	0	4	11	3½		1,413	19	1	3	4½	
1916	32,118	11	0	2	11	11	6,384	18	10	10	3¾		1,159	10	2	1	10½	
1917	45,892	10	5	3	18	5	10,680	15	2	18	3		1,603	13	10	2	9	
1918	36,993	17	6	5	1	1½	5,557	17	2	15	2¼		1,582	11	1	4	3¾	
1919	44,089	7	9	4	10	6½	7,846	13	6	16	1		2,341	3	1	4	9½	
	313,929	0	0	3	2	9½	60,632	5	8	12	1½		17,157	15	11	3	5¼	

During the period from 1905 to 1916 the cost ranged from £2 14*s.* 6*d.* to £3 14*s* 3½*d.*, being usually under £3 10*s.* a ton. The effect of the high prices for commodities induced by the war is seen in the cost of manufacture of the three closing years, 1917-19, when in 1918 it reached £6 0*s.* 7½*d.* per ton, an increase of over 70 per cent. But the value of sugar increased correspondingly, so that the cost of manufacture in this year was not at its highest, when calculated in terms of sugar, as above.

Table IV.

Cost of Manufacture.

Year.	Factory, salaries.	Per ton sugar in shillings.	Factory, wages.	Per ton sugar in shillings.	Repairs and maintenance, factory.	Repairs and maintenance, railway.	Fuel. Factory and repairing shops.	Fuel. Railway.
	£ s. d.		£ s. d.		£ s. d.	£ s. d.	£ s. d.	£ s. d.
1905 ...	1,080 18 1	13·23	828 10 7	10·13	710 0 9	183 1 10	337 8 7	57 16 0
1906 ...	1,372 3 2	11·69	1,182 17 10	10·08	1,368 9 7	1,005 18 1	139 15 6	75 0 0
1907 ...	1,515 6 9	7·00	1,790 17 11	8·47	2,363 14 7	1,556 0 0	185 6 6	220 7 4
1908 ...	1,775 1 11	7·56	2,398 7 11	10·22	2,528 18 9	1,858 10 5	666 11 11	473 0 8
1909 ...	2,025 16 10	10·14	2,469 10 6	12·36	1,214 14 11	965 5 4	361 14 3	476 0 0
1910 ...	2,227 2 8	8·26	2,913 17 2	10·81	2,922 4 8	1,879 6 8	463 16 7	582 19 4
1911 ...	2,906 7 7	10·62	3,340 14 8	12·21	3,885 13 2	985 14 6	679 14 4	581 3 9
1912 ...	3,063 6 9	9·82	3,623 3 0	11·61	4,568 4 3	3,700 8 6	1,279 5 3	585 3 6

TABLE IV.—(*Concluded.*)

COST OF MANUFACTURE.

Year.	Factory, salaries.	Per ton sugar in shillings.	Factory, wages.	Per ton sugar in shillings.	Repairs and maintenance, factory.	Repairs and maintenance, railway.	FUEL	
							Factory and repairing shops.	Railway.
	£ s. d.		£ s. d.		£ s. d.	£ s. d.	£ s. d.	£ s. d.
913 ...	3,126 17 4	8·53	4,052 3 10	11·05	4,914 15 4	2,280 9 4	1,938 17 9	582 9 9
914 ...	3,435 3 9	7·52	4,141 13 3	9·07	6,352 12 3	2,619 4 0	2,068 6 11	870 14 10
915 ...	5,013 5 9	11·95	4,171 12 4	9·94	7,556 16 0	2,810 1 3	1,540 5 7	1,269 17 10
916 ...	6,259 19 0	10·12	4,597 7 6	7·43	10,779 5 8	4,338 13 2	115 0 10	1,472 6 8
917 ...	6,791 1 5	11·60	6,038 2 0	10·36	18,793 15 3	7,513 10 7	61 12 10	2,503 8 4
918 ..	7,630 13 0	20·80	5,090 9 7	13·91	14,873 4 4	2,420 16 11	197 19 3	2,441 3 2
919 ...	6,984 15 6	14·34	6,633 11 2	13·62	14,698 6 4	4,697 7 3	506 11 1	2,459 6 4
	55,207 19 6	11·05	53,302 19 3	10·66	97,530 15 10	38,814 7 10	10,542 7 2	14,650 17 6

The average cost of manufacturing a ton of sugar during the whole period has been £3 18*s.* 4¼*d.*, which may be analysed as follows :—

	Shillings per ton.	Per cent. of total cost.
Salaries	11·05	14·10
Wages	10·66	13·60
Repairs and maintenance, factory ...	19·50	24·88
Repairs and maintenance, railway ...	7·76	9·91
Fuel, factory	2·11	2·69
Fuel, railway	2·93	3·74
Bags, stores, insurances, lighterage, etc. ...	24·34	31·07
	78·35	99·99

During the three years of high prices, 1917, 1918, and 1919, these items work out as follows :—

Average cost of making 1 ton of sugar, £5 8*s.* 9¾*d.*

	Shillings per ton.	Per cent. of total cost.
Salaries	14·91	13·70
Wages	12·33	11·33
Repairs and maintenance, factory ...	13·66	12·55
Repairs and maintenance, railway ...	10·16	9·34
Fuel, factory	·50	·47
Fuel, railway	5·16	4·75
Bags, stores, insurances, lighterage etc. ...	52·09	47·85
Total	108·81	99·99

TABLE V.
MOLASSES SOLD.

It may be interesting to record the receipts from the sale of molasses. These have been as follows :—

Year.	Value of molasses sold.			Value per ton. of sugar.		
	£	s.	d.	£	s.	d.
1905	1,685	4	4	1	0	8
1906	1,232	12	10		10	6
1907	1,235	1	9		5	10
1908	1,873	8	8		7	11
1909	3,285	12	7		16	6
1910	2,569	14	9		9	6
1911	3,193	3	3		11	9
1912	3,642	10	11		11	9
1913	3,027	19	9		8	3
1914	2,194	3	0		4	8½
1915	4,638	8	9		11	1
1916	9,291	19	11		15	0
1917	28,222	19	11	2	8	3
1918	27,591	19	7	3	15	5
1919	11,837	6	2	1	4	3¾
	105,522	6	2	True Aver.	18	9½

TABLE VI.
CANES PURCHASED.

Year.	Original contracting proprietors.	New contracting proprietors.	Peasants.	Total.
	Tons	Tons.	Tons.	Tons.
1905	15,334	344	182	15,860
1906	1[illegible]95	8,970	1,811	24,676
1907	28,046	8,689	4,047	40,782
1908	26,912	12,905	3,243	43,060
1909	20,577	14,646	2,062	37,285
1910	24,066	20,712	3,542	48,320
1911	22,507	29,398	3,211	55,116
1912	24,228	32,478	2,664	59,370
1913	23,374	44,880	2,095	70,349
1914	26,355	53,751	2,924	83,030
1915	21,308	57,993	2,219	81,520
1916	33,968	72,568	5,930	112,466
1917	25,797	71,172	5,624	102,593
1918	16,268	46,117	1,897	64,282
1919	22,495	64,957	2,734	90,186
	350,130	534,580	44,185	928,895

The sources from which the canes supplied to the factory have been derived are shown in Table VI. This table indicates the increasing supplies from new contracting proprietors, this being the result of enlargement of the factory in order to accommodate them. At the same time the table indicates the effect of varying seasons, due mainly to irregularities in the rainfall.

The distribution of the cane supply amongst the three classes of contributors during the whole period has been as follows:—

Original contracting proprietors	...	37·70 per cent.
New contracting proprietors	...	57·55 „ „
Peasants	...	4·75 „ „
		100·00 „ „

The prices paid for canes to the original and new contracting proprietors are given in Table VII, in terms of money and of sugar per 100 of cane, together with the corresponding price at which the sugar was sold. Peasants' canes were paid for on the 4½ per cent basis during the whole period.

TABLE VII.
PRICES PAID FOR CANES.

Year.	Price of sugar.	Original contracting proprietors.		New contracting proprietors.	
		Price paid per ton cane.	Equal to lb. sugar per 100 lb. cane.	Price paid per ton cane.	Equal to lb. sugar per 100 lb. cane.
	£ s. d.	£ s. d.		£ s. d.	
1905	12 15 5	14 1	5·50	...	...
1906	8 4 8	7 5	4·23	...	...
1907	9 16 0	12 3	6·25	...	...
1908	11 15 9	15 11	6·75	...	...
1909	10 7 5	14 0	6·75	...	...
1910	12 16 8	18 1½	7·07	14 6	5·66
1911	10 11 5	10 10½	5·14	12 2	5·76
1912	13 5 3	16 10½	6·37	15 10½	5·99
1913	9 8 7½	11 3½	5·99	10 8	5·65
1914	9 1 6	11 3½	6·22	10 7½	5·86
1915	16 7 9	15 8	7·60	11 5	6·53
1916	17 13 8	10 1½	8·52	14 11½	7·05
1917	19 3 5	16 0	9·39	19 1	7·59
1918	20 8 0	19 0½	9·57	19 4	7·19
1919	24 14 1	21 8	8·43	13 5	6·76

While the financial affairs of the Antigua factory are of considerable general interest, equal importance attaches to the technical work in the manufacture of sugar. Originally equipped with a 6-roller mill which was operated for two seasons, a Krajewski crusher was added in 1907, and the plant was worked as an 8-roller mill up to and including the season of 1910; six additional rollers were then added, and the mill became a 14-roller one in 1911, and remains so up to the present time.

The general results of the factory's working are given in Table VIII. It will be observed that in 1905 there was extracted

by the mill 81·7 per cent. of the sugar contained in the cane With the use of the 14-roller mill in recent years this has been increased to a figure averaging over 91 per cent., but varying somewhat from year to year: the highest efficiency in this connexion was reached in 1918, when 93·8 per cent. of the sugar in the cane was recovered in the juice. In 1919 it was 92·4.

TABLE VIII.

Year.	Purity of diluted juice.	Fibre per 100 parts of cane	Sucrose per 100 parts of cane.	Sucrose extracted per 100 cane.	Sucrose in juice per 100 sucrose in cane.	Juice lost in megass per 100 fibre.	Sugar made per 100 sucrose in juice.	Commercial sugar made per 100 sucrose in cane.	Sucrose in sugar sold per 100 sucrose in cane.
1905	89·2	15·1	15·3	12·5	81·7	92·2	8·26	67·5	64·9
1906	83·0	15·2	14·1	11·4	80·8	103·2	84·3	68·1	65·4
1907	87·3	15·1	14·4	12·1	84·4	80·4	85·5	72·2	69·4
1908	86·5	15·2	14·3	12·3	85·8	71·6	89·4	76·7	73·6
1909	85·8	15·6	14·2	12·1	85·6	71·7	89·1	76·3	73·2
1910	86·8	15·9	14·7	12·5	85·5	71·1	89·0	76·1	73·1
1911	81·2	15·5	14·1	12·1	85·7	70·3	82·2	70·5	67·4
1912	83·9	17·5	14·2	12·1	84·9	59·1	87·0	73·9	71·0
1913	83·0	17·7	12·9	11·8	91·1	36·6	88·7	80·8	77·5
1914	84·7	16·6	13·5	12·2	90·6	42·8	90·2	81·7	78·3
1915	83·1	16·9	12·0	11·0	91·4	40·5	93·9	85·3	82·7
1916	84·0	16·2	12·5	10·6	92·2	38·0	95·4	88·0	84·5
1917	84·8	17·4	13·0	12·1	93·0	31·1	94·6	88·0	84·6
1918	83·7	16·1	13·1	12·3	93·8	30·6	92·6	86·9	83·5
1919	83·1	16·7	12·3	11·4	92·4	35·9	95·1	87·9	84·4

Very considerable improvement has been effected in the recovery of commercial sugar from the sugar in the juice. In the first year of the factory's working the quantity of commercial sugar recovered was 82·6 per cent. of the weight of sugar in the juice; in 1919 it was 95·1 per cent.

When the combined work of the mills and of the manufacture of sugar from the juice is considered, it is seen that in the first year of the factory's working, 1905, the weight of

commercial (96°) sugar recovered was 67·5 per cent. of the weight of sugar in the cane; in 1919 it was 87·9 per cent., an increase in efficiency of 30·2 per cent. over the earlier figure, or, stated in another form, the loss in the first year was equivalent to 23·2 per cent. when compared with the work of 1919.

The canes dealt with have been of moderate quality. It is a matter for comment that the sucrose content has shown a decided downward tendency during the period of the factory's working, for whereas the canes contained over 15 per cent. of sucrose in the first year, they contained only 12·3 per cent. in 1919, and only 13·0 and 13·1 in the years 1918 and 1919, respectively. The reason for this marked decline in the quality of the cane is not entirely understood. Various explanations have been suggested, amongst the most plausible being that there is greater delay than formerly between the cutting and the crushing of the canes, and that deterioration occurs in consequence, or that a greater proportion of the unripe top of the cane is now sent to the mill than was formerly the case. It is also suggested that, owing to late reaping, late planting, and late supplying, a greater proportion of unripe canes now goes to the mill than formerly. It may well be that all these causes can contribute to the falling off in saccharine richness of the canes handled by the factory. These matters deserve the consideration of all those concerned, whether they are interested in the field or the factory.

It will be seen that the fibre content of the canes is very high, and this is undoubtedly a characteristic of the canes grown in Antigua. Owing to the great difficulty experienced in determining the fibre in canes, accentuated in the case of this factory by the fact that in the period under review the actual quantity of water used in maceration was not accurately known, it is felt that the returns may be somewhat high. It is hoped that in future years it will be possible to check more carefully the estimation of the fibre contents of the canes, owing to the fact that the quantity of maceration water is being recorded, and it will be interesting to compare the results.

The degree to which the factory has been enlarged can be appreciated to some extent by the following brief comparison of the main features of its equipment in 1905 and in 1919. The lists include the principal items only. It will be evident to those having expert knowledge that extensive additions and improvements in other directions are implied, and have been given effect to.

MAIN ITEMS OF EQUIPMENT.

1905.	1919.
BOILERS.	BOILERS.
Three Babcock and Wilcox water tube boilers, each 5,764 sq. feet heating surface.	Three Babcock and Wilcox water tube boilers, each 5,764 sq feet heating surface.
	One ditto, 2,000 sq. feet heating surface.

MILLS.	MILLS.
Two 3-roller mills, 30 × 60 inches, driven by one engine having cylinder 26 in. diam., 4-foot stroke.	One Krajewski crusher 24″ × 60″, driven by separate engine, having 18″ cylinder and 3-foot stroke.
	Four 3-roller mills 39″ × 60″ in train, driven by two engines having cylinders 26″ diam. and 4-foot stroke.
Mills are fitted	with toggle gear.
	Revolving cane knives fixed before Krajewski crusher. Set cane rakes for discharging canes from trucks to carrier, driven by an independent vertical engine.
JUICE HEATERS.	JUICE HEATERS.
Two horizontal, each having 500 sq. feet heating surface.	Two horizontal, each having 500 sq. ft. heating surface. Two, horizontal, each having 600 sq. feet heating surface.
EVAPORATING PLANT.	
One triple effect, having 4,000 sq. feet heating surface.	Two triple effects, each having 4,000 sq. feet heating surface, converted into a quadruple effect by addition of a first vessel common to both, having 3,000 sq. feet heating surface.
Two vacuum pans, each capable of striking 15 tons massecuite or 10 tons dry sugar, each having coils with 450 sq. feet heating surface.	Two vacuum pans, each capable of striking 15 tons massecuite or 10 tons dry sugar, each having coils with 450 sq. feet heating surface. One vacuum pan capable of striking 30 tons massecuite or 20 tons dry sugar, calandria type, having 1,100 sq. feet heating surface.
One condenser, Torricellian type.	One vacuum pan capable of striking 2 tons dry sugar, having wet air pump.
	Two condensers, Torricellian type.
Six crystallizers with worm stirring gear, each 3,000 gallons capacity.	Thirteen crystallizers, with worm stirring gear, each 3,000 gallons capacity.

CENTRIFUGALS.	CENTRIFUGALS.
Five belt-driven, with 36″ baskets.	Twelve for 1st sugar, water-driven, with 36″ baskets. Twelve, belt-driven, for 2nd sugar, with 36″ baskets.
RAILWAY.	**RAILWAY.**
Six miles, laid with 30 lb. rails. Two 7-ton locomotives, cylinders 7″ × 12″.	Twenty-one miles, laid with 30lb. rails, 30 gauge. Three 7½-ton locomotives, cylinders 7″ × 12″. Four 12-ton locomotives, cylinders 9″ × 15″, 339 cane trucks wood, 77 cane trucks steel.

All those connected with the enterprise—the directors, manager, and staff of the factory, and the contracting proprietors supplying canes—are to be congratulated on the successful manner in which the contracts, plans, and aspirations of the venture have been carried out. The factory and its manner of working, including the lines of co-operation with the estates proprietors, were planned at a time when there was very little definite information to guide those who were concerned in shaping events, and matters were not rendered easier by the fact that great changes in the sugar industry were impending. When the work first began the shadow of bounty-fed beet sugar lay heavy upon the British Colonial sugar industry, and it was essential that the new development should be directed in proper channels, and there were grave fears as to the stability of that industry. Fortunately, the early steps practically coincided in point of time with the measures taken to combat the effects of the sugar bounties by means of the Brussels Convention, but the position was by no means a stable one. There were no large sugar factories in the neighbouring islands which might serve as models and guides in the venture, while there was great uncertainty as to the results which a factory might show, when dealing with the material which would come to it—what tonnage of cane, for instance, would be required to make a ton of sugar, or what proportion of the sugar might be effectively turned into the manufactured article. The factory was a pioneer one in a very real sense, and it was largely in recognition of this fact that Imperial financial assistance was forthcoming. The factory has well fulfilled the function of exemplar to similar undertakings. At the outset, before even the plans for the machinery had been prepared, it was decided by the directors that the entire work of the factory must be conducted on lines which would afford the fullest statistical information, particularly in regard to the chemical aspects of the canes, and the subsequent products during the course of manufacture; and not only that this information should be available for the use of those responsible for the operation of the factory, but that these facts should also be available for general information. This course has been followed throughout. The work of the laboratory has been as complete and accurate as circumstances have permitted, and the operations of the factory have been effectively guided by the information

furnished by the scientific staff, including in this term not only the chemical, but also the engineering and accounting staffs. The general information so obtained has been furnished in its main features to the Imperial Department of Agriculture, and has been published at intervals for general information. This complete co-operation of technical, scientific, and Government interests is deserving of notice and record : the results have been useful, and the interests of the British West Indian sugar industry have been considerably advanced thereby. There has been a steady record of progress and development in this industry during the last ten or fifteen years, and it may reasonably be claimed that much of the success achieved in this progress has been due to the knowledge rendered available through the work of the Antigua factory.

When the factory was installed in 1905, single crushing, that is to say, the manipulation of the canes by means of 3 roller mills, was general in the British West Indies, with perhaps one or two exceptions. The installation of even the 6-roller mill with which the factory was first equipped was in the nature of an innovation ; the addition, two years later, of a Krajewski crusher was a distinct advance, while the conversion of the milling train into a 14-roller one in 1911 instituted the first of such mills in these islands. In the general matter of sugar manufacture, as distinguished from the extraction of the juice from the canes, the Antigua factory has done pioneer work, and disseminated information which has been of general service.

In 1905 the production of muscovado sugar was general in the British West Indies, and fears for the stability of the industry were entertained on that account, for the refiners were expressing dissatisfaction with this class of sugar, and were evincing a decided preference for crystal sugars made in the vacuum pan. The developments undertaken at Antigua paved the way for the manufacture of vacuum pan sugar in modern factories in these islands, so that to day there are very few small works left where ordinary muscovado sugar is being made.

Not only was the factory itself in the nature of a pioneer venture, but the manner in which the cane growers were brought into co-operative relationship with the factory in the matter of furnishing canes and participating in profits was entirely new. There was much hesitancy concerning the soundness and safety of the propositions, and only a limited number constituted the group of original contracting proprietors. Owing to the successful working of the original plans these have now been augmented by a body of new contracting proprietors, but these latter do not obtain the advantage of becoming possessed of shares representing one-half of the factory, as the original contractors have.

Novel as the contracts were, and lacking as the conditions of the time were in information—financial, technical, and general —for the guidance of the promotors, it is a matter for congratulation and satisfaction that the period of the original contracts has been completed, without any serious difficulties arising, and that the factory starts on the second phase of its existence with bright prospects.

The effects of the war upon agricultural and commercial matters have perhaps been felt in as marked a degree in

connexion with sugar as with any other commodity, for the sugar supplies of the United Kingdom were, up to the time of the war, derived largely from Germany and Austria, and under such conditions as to exclude to a large extent British colonial sugar from this market. The utter collapse of supplies from these continental sources, together with the almost complete failure of Russia to produce sugar, has caused what, at times, has almost amounted to a sugar famine in the United Kingdom.

Germany and Austria are at present barely able to produce the sugar required for their own consumption, while Russia, which just prior to the war produced and consumed very large quantities, and exported some, is now producing practically none, and is suffering from a sugar shortage which creates a demand on outside supplies. Coupled with this disruption of production comes increased consumption in certain countries, notably in the United States. In consequence of all these disturbing conditions there is at present something in the nature of a world-wide sugar famine, and prices have risen to famine level. In these circumstances it is impossible to forecast the future. It would however seem evident, that high prices, though probably not the high prices of to-day, must obtain for some few years. These high prices will rapidly stimulate production, so that when the decline in price sets in it may be a rapid one, and it will require all the resources of modern sugar factories to meet the competition which will thus result.

A further circumstance which is practically certain to affect the manufacture of sugar, and influence the work of tropical sugar factories, is that there is a growing tendency to produce on the spot where the sugar is grown, sugar fit for consumption, and to eliminate to a large extent the work of the refiner. This tendency is already stimulating the owners of modern factories in the tropics to efforts to ascertain how effect can best be given to these ideas. As the outcome of all this, attention is being given to new processes, most of which involve the exercise of much skill in their operation. It is probable that success will ultimately attend these efforts, and that the methods of sugar making will again be materially changed. These developments, when they mature, will necessitate the application of greater and greater technical skill, thus requiring the employment of thoroughly trained, competent men for the direction of the affairs of the sugar factories; and it is more than probable that the manufacture of sugar under these altered conditions will have to be carried on in factories of considerable size, and elaborately equipped.

In any case the future of the sugar industry appears to be full of hope and encouragement, and to be one in which there will be scope for the exercise of great originality and skill, thus offering attractions for those who engage in it in the future. The progress started by the pioneer factories of to-day will have to be continued with sustained energy, coupled with technical skill of a high character.

The Antigua factory did something to foster the progress which has been apparent n the past decade, and it may be hoped that it will acquit itself creidtably in the new era which now opens.

[Pages 77—155 issued 30th October, 1920.]

THE WATER-BALANCE OF THE PLANT AND ITS SIGNIFICANCE IN CROP PRODUCTION.

BY T. G. MASON, M.A., Sc.B., Agr.B.,
Botanist on the Staff of the Imperial Department of Agriculture for the West Indies.

INTRODUCTION.

The ascent of sap in plants, though long a much debated problem, was first put on a rational physical basis by the researches of Dixon [16] [17] and his colleagues. The earlier theories, most of which involved a somewhat vague pumping action of the living cells, were subjected to a searching analysis by Dixon, and though they lingered on for a time, have now appearently been definitely abandoned. The Cohesion theory is now so well known that it need not be considered here in any great detail.

The theory is based on the fact that the plant sap has a very great tensile strength, and in this respect does not differ essentially from water. The physics of the ascent of sap may be illustrated by means of an artificial plant consisting of two porous pots connected hermetically by a very fine capillary tube a couple of metres in length, the pots and tube being completely filled with water. The lower one, which functions as the root of the artificial plant, is inserted in moist soil, while the upper one is supported in the air above. As evaporation proceeds from the upper pot, the volume of water in the instrument tends to decrease, and the water-films on its surface to become more stretched. The increased surface tension there causes a concomitant increase in the tension in the liquid inside. If contact has been established between the soil water-films and the water in the lower pot, the tension thus generated is transmitted not only throughout the instrument, but also to the soil solution.

If the surface tension in the water-films on the surface of the upper pot is exactly balanced by the forces with which the soil retains its moisture, there will be no movement of water through the instrument. If, on the other hand, the former exceeds the latter, water will pass from the soil into the instrument. The magnitude of the tension in the water of the instrument is therefore proportional to the desiccating power of the air, which determines the rate of evaporation from the upper pot, and to the back-pull due to the water-attracting power of the soil. The rate of movement is a function of the gradient in the tension, i e. the excess of the upward pull, due to evaporation over the back-pull of the soil. Air and soil may each be regarded as exerting a force tending to remove water from the artificial plant.

The desiccating power of the air [40 41 44 9] is expressed as the number of weight units of water evaporated in unit time from some standard atmometer. An atmometer is any instrument employed for the measurement of evaporation. The Livingston radio-atmometer, which is probably the most satisfactory form, consists of a black spherical porous pot to which is attached a short tube leading to a water reservoir. The desiccating power of the air is registered by the rate of water loss from this reservoir.

The water-attracting power of the soil, [56 44 45] or its reciprocal, the water-supplying power of the soil, is more difficult to determine, but may now be measured by means of Livingston's and Koketsu's [45] soil-point method, and, like the desiccating power of the air, is expressed as a rate. The number of weight units of water imbibed in unit time by unit cross-sectional area of a hollow porous porcelain cone affords a simple means of estimating the aridity or desiccating power of the subterranean environment. The effective aridity of the environment as a whole, Livingston points out, should therefore be proportional to the product of the desiccating power of the air and the water-attracting power of the soil, for together they furnish a measure of the tendency of the environment to remove water from the plant.

It should be evident then, that the tensions in the water in the capillary tube of our artificial plant would serve as an index to the aridity of the environment as a whole, for this tension is determined by the combined tendencies of both air and soil to remove water from the instrument. This is not the case in the plant itself, however, for no constant relation need exist between the tension in the water in its conducting tracts and the aridity of the environment. There are a number of reasons for this, among which may be mentioned the following. The plant itself, unlike the artificial plant we have been considering, does not maintain any constant relation between the area of its absorbing and evaporating surfaces. The greater the extent of the leaf area and the smaller the root area, for instance, the higher generally will be the tensions in the water tracts. Individuals of the same strain of plant also show, according to the conditions under which they are grown, fluctuations in height, the conductivity of the water tracts (Farmer), [22] and the

transpiring power of the leaf (Shreve)[63]. Transpiring power* or relative transpiration ratio (the transpiration coefficient of Briggs and Shantz) [8] is a term introduced by Livingston to denote the intrinsic ability of the leaf to give off water vapour. It represents all the conditions within the leaf, retarding or accelerating transpiration. The divergences in this characteristic between different species of plant are so pronounced that it has been suggested that plants may be classified on this basis into hygrophytes, mesophytes, and xerophytes. Variations as already indicated, also occur to some extent between individuals of the same species of plant in different habitats and in neighbouring leaves of the same plant, and even in a single leaf in the course of a day.

It will be patent, therefore, that no constant relation need exist, even in individuals of the same species, between the tensions in the water in their conducting tracts and the aridity of the environment, though a high degree of correlation between these factors should normally prevail. High rates of transpiration, for instance, in a soil whose power of supplying water to the roots is small, will normally be accompanied by greater tensions than low rates of transpiration in a soil of high water-supplying power.

THE WATER-ABSORBING POWER OF THE CELL.

Though some investigators have assigned an important rôle to the cell colloids in the absorption of water and the distention of the cell wall, there is no doubt that in the normally vacuolated cells of plants the osmotic pressure of the cell, acting against an elastic wall, plays the chief part in the development and maintenance of the turgor pressure of the cell. Livingston ([39]) has pointed out that the forces of imbibition exerted by the cell colloids must in every static case be in equilibrium with the osmotic pressure in the cell vacuoles. Were it otherwise, water would either enter or leave the gel complex, and this would continue till the attainment of equilibrium. Attention will accordingly be focussed on the part played by the osmotic pressure of the cell in the absorption of water and the development of turgor pressure.

When an isolated plant cell is immersed in water, a movement of water into the interior of the cell is determined by the ions and molecules in solution in the cell sap. This absorption of water distends the cell wall, which is elastic, and therefore exerts a pressure which compresses the cell contents. The hydrostatic pressure thus set up is known as the turgor pressure of the cell. It is evidently equal and opposite to the inwardly directed components of the tensions in the cell walls. It may be regarded as tending to force water out of the cell.

*The transpiring power of the leaf is expressed as a ratio. It is numerically equal to the rate of transpiration from unit area of the leaf for a given period divided by the rate of evaporation for the same period from unit area of some standard evaporating surface. If the rate of transpiration from the leaf is represented by T, and if E represents the rate of evaporation for the same period, then the transpiring power of the leaf or plant, as the case may be, equals $\frac{T}{E}$.

After this absorption of water has continued for a time, a condition of equilibrium is attained, and no more water enters the cell. The cell is then said to be fully turgid. In this condition the osmotic pressure is exactly balanced by the turgor pressure, so that T = P, where P represents the osmotic pressure of the cell, and T the turgor pressure. That is to say, the osmotic pressure tending to distend the cell is equal to the inwardly directed components of the tensions in the elastic cellulose membrane, which of course tend to compress it.

If for any reason the osmotic pressure be increased or the turgor pressure be decreased, the cell is again capable of absorbing water. The osmotic pressure is no longer balanced by the turgor pressure, for P becomes greater than T. The excess of the osmotic pressure over the turgor pressure thus determines what Thoday [68] designates the water-absorbing power of the cell. It is numerically equal to that part of the osmotic pressure which is not balanced by the turgor pressure. Thus P – T = the water-absorbing power of the cell. It will therefore be realized that there is no necessary relation between the osmotic pressure and the ability of a cell to absorb water, for it is only that portion of the total osmotic pressure that is not employed in the distention of the cell wall which is available for the absorption of water. Thus two contiguous cells may differ widely in osmotic pressure, and yet may have identical water-absorbing powers.

The water dynamics of the mesophyll cell of the leaf may now be briefly considered. For simplicity we will suppose that one side of the cell wall abuts on a xylem vessel, and that the other is exposed to the desiccating influence of the air in the intercellular space of the leaf.

It will also be assumed that the cell is completely turgid, so that P – T equals zero. As moisture is evaporated into the internal atmosphere which bathes the cell on one side, the surface tension of the water films in the exposed cell membrane increases, and water is withdrawn from the interior of the cell. The solutes of the cell sap are thus concentrated, and the osmotic pressure augumented, while the turgor pressure of the cell is correspondingly diminished. In this way the water-absorbing power of the cell is increased to meet the growing surface tensions in the water-films from which evaporation proceeds. The water-absorbing power might also be increased by means of the introduction of solutes into the cell, (e.g. during photosynthesis); in this case no loss of turgor pressure would result. It must, however, whatever the means of adjustment, tend to reach a condition of equilibrium with the surface tension in the water films where evaporation is taking place. Were it otherwise, water would either enter or leave the cell until the attainment of equilibrium.

It is now necessary to consider the effect of the tension in the xylem vessel. A column of water hanging stationary from the leaf peripheries is of course in a state of tension, the magnitude of which is determined by the hydrostatic head. As soon, however, as water moves through the conducting tracts to replace the losses due to evaporation from the exposed walls of the mesophyll cells, an additional factor comes into operation.

This is the frictional resistance opposed by the conducting tracts to the movement of water. The internal resistance of the liquid is probably a negligible factor. The resistance of the conducting tracts of course operates to increase the tensions in the water columns. The resistance and therefore the tensions, vary according to the rate of flow of the ascending sap. It will be evident that the water absorbing power of the mesophyll cell must tend to reach a condition of equilibrium with this tension in the water in the adjacent xylem vessel. For static equilibrium we therefore obtain the expression

$$S = (P - T) = C$$

where S represents the surface tension in the water films of the cellulose membrane from which evaporation into the intercellular spaces of the leaf takes place, and (P – T) as before, denotes the water-absorbing power of the cell, in this case the mesophyll cell; while C is the tension in the water in the xylem vessel in contact with the mesophyll cell.

It will be patent then, that the water-absorbing power of the leaf cell must adjust itself to every change occurring either in the tensions in the water in the conducting tracts, or in the surface tension of the water-films in the exposed cell walls. It will simplify subsequent discussion if we refer to the latter as the forces of imbibition in the walls of the mesophyll cells. The factors which determine these imbibitional forces and the tensions in the water tracts are intimately correlated. High rates of transpiration, for instance, must be balanced by corresponding rates of flow of water up the plant, and thence into the foliar cells; otherwise more water will be evaporated from the leaves than enters from the vessels. If this is continued, the leaf wilts, and eventually the cells become irreversibly plasmolysed . . The pull, however, which is exerted by the imbibitional forces in the walls of the mesophyll cells is transmitted through the cell to the water in the conducting tracts, so that the tensions there are increased, and the rate of flow augumented.

Conversely, any increase in the tensions in the water tracts, whether due to a decrease in the water-supplying power of the soil or for any other reason, must lead to greater forces of imbibition in the evaporating surfaces of the leaf. It will be well therefore to examine these factors one by one, and to endeavour to trace their effects on the water-absorbing power of the cell. It is hoped that by following this procedure it may be possible to arrive at some conclusion concerning the means normally adopted by the plant cell to adjust its water-absorbing power to the needs of its environment. Such an analysis is evidently a pre-requiste to an appreciation of the significance of the water balance of the plant.

THE HEIGHT OF LEAF INSERTION AND THE WATER-ABSORBING POWER OF THE CELL.

That the tension in the water tracts of a plant, whose leaves are transpiring at a uniform rate, must increase from the lower to the upper levels will be obvious; for at the upper levels both the load due to the water columns hanging from the leaf

peripheries, and the resistance of the conducting tracts opposing the upward movement of the sap, are greater than at the lower levels. Both hydrostatic head and frictional resistance of the conducting tracts effect this augmentation in tension in the water in the upper regions of the plant. It follows of course that this gradient in the tension in the water columns is accompanied by a similar gradient in the water-absorbing power of the living cells of the plant. This gradient in the water-absorbing power of the living cells may or may not involve, as was indicated in the last section of this paper, a corresponding gradient in the osmotic concentration of the cell sap, for the former is determined solely by the excess of the osmotic over turgor pressure. If the turgor pressures of the cells at all levels of the plant were to remain approximately constant however, then a gradient in the osmotic pressures of the cell sap would necessarily ensue.

An investigation of the osmotic pressure of the leaf sap at different elevations on the plant has been carried out by Harris, Gortner, and Lawrence [29]. As a result of an examination of twenty-six trees belonging to twelve different species, they found that a high degree of correlation existed between the height of leaf insertion and the foliar osmotic pressure ; the osmotic pressure increased almost without exception from the lower to the higher levels. Inasmuch as their investigations were concerned solely with the height of the leaf above the ground, and therefore took no account of the length of the branch through which the sap travelled, their results are necessarily not as conclusive as they might have been, had it been possible to take the latter factor also into consideration ; for the resistance opposed by the conducting tracts is naturally a function of the distance through which the sap travels on its way from the roots to the leaves. Their investigations demonstrate conclusively, however, that the foliar osmotic pressure increases from the lower to the upper levels of the trees. It may be tentatively concluded accordingly, that the water-absorbing power of the mesophyll cell is adjusted to the tension in the water tracts by changes in the osmotic pressure. Information as to magnitude and fluctuations in the turgor pressures of plant cells is still, however, extremely meagre. Salmon and Fleming [60] have attempted to determine the turgor pressures of wheat and oats seedlings, by observing the osmotic pressure of the cell before and after wilting. So far as the writer is aware this is the only attempt that has been made to determine the turgor pressures in plant cells.

Harris and Lawrence [27] have also determined the osmotic pressures of a number of plants growing in the Tucson region of the Arizona Desert. Considerable variations were found to exist between plants of different habit. Thus, the mean foliar osmotic pressure of trees was found to be 28·10 atmospheres, of dwarfs and half shrubs 21·45 atmospheres, of perennial herbs 16·35 atmospheres, and of annuals only 14·73 atmospheres. Here, too, there is evidently a correlation between the length of the conducting tracts and the foliar osmotic pressure.

It has been frequently asserted in the past that the magnitude of the foliar osmotic pressure was largely dependent on the illumination to which the leaf was exposed. It was considered,

for instance, that the greater osmotic pressure in the upper regions of the tree was due to a larger accumulation of soluble carbohydrates resulting from greater photosynthetic activity there. The present writer's work [49] on the electrolytes of the leaf sap, indicates that where the conditions are favourable for photosynthesis, the non-electrolytes of the leaf sap assume a greater importance in the maintenance of the osmotic pressure, but that the total osmotic pressure is in no way defined by the rate of photosynthsis. There is no doubt, as Chandler [13] has shown, that the part played by the sugars in the production of the osmotic pressure of the leaf has in the past been greatly over-estimated.

THE DESICCATING POWER OF THE AIR, AND THE WATER-ABSORBING POWER OF THE CELL.

The desiccating power of the air, as determined by the Livingston radio-atmometer, is presumably a function of the vapour tension of the air. which bathes the evaporating surface, the radiant energy absorbed by the instrument, and the velocity of the wind. Livingston [40] [41] has frequently emphasized the importance of the nature of the evaporating surface ; he points out that it often plays as great a rôle in determining the rate of water loss as do the atmospheric conditions. It is essential, therefore, when comparing the desiccating power of the air of different habitats, or of different periods for the same habitat, that atmometers should be employed which are similar as to size, shape, material, and colour. In other terms, it is essential that a standard instrument should always be employed.

It will readily be understood that though transpiration from the leaf, and evaporation from the atmometer are influenced by similar environmental factors, yet the response of the two systems, plant and atmometer, may differ somewhat, when both are subjected to the same external conditions. The ratio between the rate at which water is lost in plant transpiration, and the rate of loss from the atmometer, should give a straight line when plotted as a graph, if both systems responded alike to changes in the environment. Though this condition is never attained, it is now abundantly evident that the environmental factors responsible for the loss of water from the atmometer are identical with those affecting transpiration, and further that the variations in the rate of water loss from the atmometer are generally accompanied by approximately similar variations in the rate of transpiration. In other words, the desiccating power of the air, as determined by the atmometer, is normally a reliable index to the rate of water loss from unit leaf area of any particular plant for the same period of time, provided the water-supplying power of the soil does not vary greatly. It is now possible to proceed to a consideration of the relation rate between the rate of transpiration and the water-absorbing power of the cell.

Even when transpiration is at a standstill the water film in the evaporating surfaces of the mesophyll cells and the water columns hanging from these surfaces are in a state of tensions

for even though there is no movement of water through the plant, yet the stationary water-columns are acted upon by two opposed systems of forces. The first of these, the forces of adhesion in the leaf peripheries, acts upwards. The second, the pull due to gravity on the water-column, acts downwards. The magnitude of the resulting tension is therefore a function of the height of the leaf above the roots.

As soon as transpiration commences, an additional factor is called into play. The removal of water, evaporated into the sub-stomatal air spaces from the water-films in the exposed cell membranes, causes an augmentation in the surface tension of these films. This increase in the imbibitional forces of the cell wall is followed by a withdrawal of water from the interior of the mesophyll cell, which causes a concomitant increase in the water-absorbing power of the cell. Under the influence of this, water moves up through the conducting tracts and enters the transpiring cell. A retarding force, however, is brought into operation as soon as this upward movement of sap commences. This is due to the frictional resistance of the conducting tracts, and the back-pull due to the water-attracing power of the soil. The latter is negligible of course at high moisture contents. The former, however, increases very rapidly as the velocity of flow becomes greater. If evaporation from the water-film of the leaf peripheries is rapid, and the conductivity of the water tracts is small, a considerable lag may occur between the rate at which water is removed from the transpiring cell by evaporation, and the rate at which it enters from the xylem vessels. The magnitude of this lag in the leaves of any single plant will necessarily depend to a considerable degree upon the fluctuations in the rate of evaporation from the leaves, and upon the height of the leaves above the ground, for the greater the distance through which water has to travel on its way from the soil to the leaves, the greater will be the frictional force opposed to its movement by the walls of the conducting tracts. Now this lag must operate to deplete the foliar cell of its water. This reduction in foliar moisture has been characterized by Livingston and Brown [42] as incipient drying, and by Renner [52] as the saturation deficit. It will be evident that the incipient drying of the leaf is necessarily accompanied by a corresponding increase in the water-absorbing power of the cell. The latter is therefore a function of the fluctuations in the desiccating power of the air, in so far as these variations determine the rates of transpiration, and of the forces opposing the movement of water from the soil to leaf cell.

It occurred to Livingston and Brown [42] that the magnitude of the lag between the rate at which water entered the mesophyll cells, and the rate at which it was removed by transpirations, might be sufficiently pronounced to be registered by a sensible depletion in the water content of the leaf. They accordingly initiated a series of determinations of the diurnal fluctuations in the water content of the leaves of a number of plants growing at Tucson, Arizona. Their observations proved the surmise to be correct, as may be verified by reference to Table I in which some of their results are reproduced.

TABLE I.

Evaporation.			Hour of test.	Percentage of moisture on basis of dry substance.		
Period.		C.C. per hour.		Physalis.	Nicotiana	Euphorbia.
	4–5	0·06	5	..	588·7	...
	5–6	0·06	...	...	..	...
	6–7	0·50	7	820·2	...	581·6
A.M.	7–8	1·20	...	.	..	...
	8–9	1·92	9	865·5	435·0	521·6
	9–10	2·10	10	804·6	..	—
	10–11	2·40	11	818·9	..	...
	11–12	2·58	...	...	...	...
	12–1	2·40	1	678·5	423·3	433·8
	1–2	2·88	...	..	...	...
	2–3	2·94	3	660·6	..	...
	3–4	2·70	...	...	..	...
	4–5	2·70	5	703·4	392·5	485·5
P.M.	5–6	1·92	...	...	...	..
	6–7	1·20	7	877·9	...	..
	7–8	1·20	..		.	..
	8–9	1·20	9	855·7		480·9
	9–10	0·90	...	..		..
	10–11	1·98	...	...	..	...
	11–12	1·14	...	...	...	...
	12–1	0·42	...	...	...	...
A.M.	1–2	0·42	...	.	...	..
	2–3	0·18	3			

It will be seen that the degree of incipient drying increases during the forenoon as the desiccating power of the air becomes greater, and that this saturation deficit diminishes in the course of the afternoon. Many other investigators—Lloyd [46 47 48], Shreve [61], Miller [54], McCool and Miller [52]—have arrived at similar conclusions Even in the humid Southern State, Lloyd [47] reports a marked depletion of the foliar moisture content of the cotton plant during the day. Miller [53] has pointed out that determinations of depression of the water content of the leaves should thow some light on the relative abilities of different plants to absorb water from the soil and to transport it to their transpiring regions. This suggestion appears to be wholly sound, and such determinations should furnish valuable information as to the water economy of the plant, for the degree of incipient drying is defined on the one hand, by the balance between the rates of absorption by the roots and conductivity of the water tracts, and on the other hand, by the rate of transpiration.

A reduction in the foliar water content is necessarily accompanied, as already indicated, by an augmentation of the water-absorbing power of the mesophyll cells. This is due, of course, to an increase in the osmotic pressure resulting from a concentration of the cell solutes, and a corresponding decrease in the turgor pressure of the cell. McCool and Miller [52] have shown that such a rise in the osmotic pressure actually occurs (Table II) during the forenoon, as the desiccating power of the air increases. It is pointed out, however, that the rise in the osmotic pressure of the cell sap is not entirely to be explained by a decrease in the water content of the plant, for it appears that the accumulation of sugars*, elaborated in photosynthesis, is responsible for some of the augmentation of the osmotic pressure and consequently also for some of the increase in the water-absorbing power of the cell.

TABLE II.

THE OSMOTIC PRESSURE OF ROOTS AND TOPS OF THE CORN PLANT AT DIFFERENT INTERVALS DURING THE DAY.

Time.	Tops.		Roots.
	Water content, per cent.	Osmotic pressure atmospheres.	Osmotic pressure atmospheres.
Sunrise	93·4	6·061	4·519
9.00 a.m. ...	91·8	6·867	4·676
1.00 p.m. ...	91·5	7·529	6·050
5.00 p.m. ...	92·7	6·867	5·423
10.00 p.m. ...	92·8	6·724	4·327

*Also electrolytes carried by the transpiration current.

Dixon and Atkins [2], and also the writer [49], have shown that the osmotic pressure of the sap is greater in the leaves on the southern sides of plants in northern latitudes than it is in the leaves of northern aspects. The desiccating power, and consequently the rate of transpiration, is of course greater on the southern sides. It follows also, that the water-absorbing power of the foliar cells must be greater on the southern side of the plant than on the northern.

As yet, as far as the writer is aware, no data are available as to the variations in the foliar osmotic pressure of individual plants of the same strain, when grown under uniform conditions of soil moisture, but exposed to an aerial environment of different aridities.

THE WATER-SUPPLYING POWER OF THE SOIL AND THE WATER-ABSORBING POWER OF THE CELL.

It was first pointed out by Dixon [16, 17] that the tensions generated in the water-films of the leaf peripheries and transmitted through the xylem of stem and root, afforded a sufficient explanation of the absorption of water by plant roots. His conclusions on this matter have since received confirmation from the work of Renner [58], who has shown that the water-absorbing power of the roots is directly related to the degree of saturation deficit prevailing in the transpiring leaves. A reduction in foliar water content is accompanied, as already indicated, by a rise in the water-absorbing power of the foliar cells, and a corresponding increase in the tensions in the water-columns of the plant, and this in turn leads to a more rapid rate of water flow from soil to root.

In a previous section it was pointed out that the tension in the water-columns of the plant diminishes from the upper to the lower levels. It follows, of course, that the tensions are less in the roots than in the aerial parts of the plant. The water-absorbing power of the root cells must accordingly be less than elsewhere, for $P - T = C$*. It is of interest, therefore, to find that the osmotic pressure of the cell sap has been found to be less in the roots than elsewhere. Some of Dixon's and Atkins's [2] results show that there is a difference of almost four atmospheres between osmotic pressures of the cell saps of the tops of the leaves and the roots of *Iris Germanica*. There is, as was pointed out in a previous section, a gradient in the osmotic pressure of the cell sap as well as in the tensions of the water-columns of the plant. Such a condition is of course a natural, though not a necessary consequence of the cohesion theory. It is not a necessary consequence, since the gradient in the water-absorbing power of the cells might conceivably have been due to turgor pressure differences. The mechanism of water absorption by the root should however be treated in greater detail, for there are probably few phases of the water dynamics of the plant which have in the past been more thoroughly neglected.

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* P = Osmotic pressure.
T = Turgor pressure.
C = Tension in water-columns.

In order that water may enter the root hairs, it is evident that the water-absorbing power of these cells must exceed the forces of imbibition in the cell walls in contact with the soil solution, and that the latter must, in turn, exceed the forces due to the water-attracting power of the soil. It cannot be too strongly urged, that it is only that portion of the osmotic pressure of the cell sap which is in excess of the turgor pressure, i. e. (P – T), that is available for the absorption of water. For the introduction of water into the root from the soil, and its movement across the cortex and into the xylem vessels, the following conditions must be fulfilled. Firstly, the tension in the water of the conducting tracts of the root must surpass the water-absorbing power of the adjacent living cells. Water will then enter the vessels of the xylem from these adjacent cells. Secondly, the water-absorbing power of the living cells in contact with the vessels must exceed that in the peripheral cells of the root; a movement of water across the cortex then ensues. The expression for the absorption of water by the root is therefore—

$$C > (P - T) > I > S,$$

where

C = the tension in the water in the xylem vessels;

P – T = the water-absorbing power of the living cells of the roots;

I = the imbibitional forces in the cell walls in contact with the soil solution;

S = the pressure with which the soil holds its moisture, i. e. the forces due to the water-attracting power of the soil.

It will be patent, therefore, that for any single strain of plant, a close relationship should exist between not only the water-absorbing power of the root cell, but also between that of the foliar cells and the water-attracting power of the soil. The relationship, especially of the foliar cells, will depend to a very large extent on the desiccating power of the air. Some experiments of Hibbart and Harrington [36] are of interest in this connexion. They studied the effect of varying the moisture content of the soil on the osmotic pressure of the roots and tops of maize plants. They maintained, by means of Livingston auto-irrigators, soil moisture contents of from 11 to 31 per cent. It was found that osmotic pressures of the tops varied from 26·4 to 22·1 atmospheres, while the fluctuations in the roots were from 12 to 5·9 atmospheres.

It would appear that the water-absorbing power of the cell is adjusted to the water-absorbing power of the soil by means of changes in the osmotic concentration of the cell sap. Arrhennius [1], too, has demonstrated that the osmotic pressure of the cell varies directly with the water content of the soil. The water-attracting power increases of course as the moisture content diminishes. The pressure with which the soil withholds moisture from the roots is very small when the soil is nearly saturated, but increases enormously in the neighbourhood of the

wilting coefficient.* Thus, McCool and Miller [52] could trace no relationship between the water content of the soil and the osmotic pressure of the leaves until the critical water content of the soil was reached.

THE WATER-SUPPLYING POWER OF THE SOIL, AND THE OSMOTIC PRESSURE OF THE SOIL SOLUTION.

It has hitherto been assumed in this discussion, that the water-supplying power of the soil, or its reciprocal, the water-attracting power, is a function solely of the pressure with which the soil holds its moisture, and its ability to conduct moisture to the roots from the more distant regions of the soil. Livingston and Koketsu [45] have defined the water-supplying power of the soil as the capacity of the soil to operate as a system, or machine, delivering water to the absorbing surface of plant roots. It will be clear then, that when the force of imbibition of a porous-porcelain cone is employed in measuring this property of the soil, the resistance opposed by the osmotic pressure of the soil solution to the absorption of water by the root cells with their semi-permeable membranes is left out of account. It is essential, therefore, that we should see whether or no this factor can be neglected. To do this, it will be necessary to consider certain phases of the literature devoted to the osmotic pressure of the soil solution. Before doing so, however, the question at issue may be made clearer by considering the osmometer method of determining the water-supplying power of the soil, which was employed by Livingston and Pulling [56] in some earlier studies of the water dynamics of the soil moisture and its relation to the plant. A collodion membrane, stretched across the large opening of a thistle funnel, was pressed against the soil. The funnel contained a solution of sugar, and the rate at which water was supplied by the soil was recorded by the rise of the sugar solution up a collodion pipette. The rate at which an instrument of this nature withdraws water from the soil is evidently a function not only of the pressure with which the soil holds its moisture, and its ability to conduct moisture to the absorbing surface from the more distant areas, but also of the osmotic pressure of the soil solution.

Now if the variations in the osmotic pressure of the soil solution are of considerable magnitude in normally non-saline soils, it follows that the imbibitional method of the porous-preclain

* The wilting coefficient (Briggs and Shantz [7]) of a soil is defined as the percentage of moisture, expressed as a percentage of the dry weight, at the time when the leaves of the plant growing in that soil first undergo a permanent reduction in their moisture content, as a result of a deficiency in the soil moisture supply. By a permanent reduction is meant, a condition from which the leaves cannot recover in an approximately saturated atmosphere, without the addition of water to the soil. In the case of ordinary plants, wilting accompanies this reduction in water content, and is the criterion used to determine the wilting coefficient of the soil for that plant. The differences which extreme types of soil present in this respect are truly remarkable, ranging from 1 per cent. in a coarse dune sand to 30 per cent, or more in the heaviest types of clay. The wilting coefficient of the soil when determined by different species of plants shows the most remarkable agreement. According to Caldwell [11], the wilting coefficient is, within limits, a function of the desiccating power of the air.

cone cannot be employed for the determination of the water-supplying power of the soil. For it must not be forgotten that the plant, like the osmometer, in absorbing water from the soil, has to do work in overcoming not only the surface forces of the soil-water complex, but has also to reckon with the osmotic pressure of the soil solution. That the water-absorbing power of the root cells must be adjusted to the fluctuations in the osmotic pressure of the nutrient solution which bathes the roots, may be seen from the following expression :—

$$C > (P - T) > I > S + O,$$

where

C = the tension in the water of the xylem vessels ;

P – T = the water-absorbing power of the root cells ;

I = the forces of imbibition in the cell walls of the root hairs ;

S = the pressure with which the soil in contact with the root hairs holds it moisture ;

O = the osmotic pressure of the soil solution.

It will be unnecessary to refer to the work of the numerous investigators (Drabble and Drabble [18 19], Cavara [12], Fitting [23]) who have established the dependence of the osmotic pressure of the plant cells on the osmotic pressure of the solution in contact with the roots. An interesting observation, however, is that of Harris and Lawrence [28], who have found that some marine mangroves may have osmotic pressures as high as fifty atmospheres, whereas other mangroves growing in nearly fresh water may show osmotic pressures of not more than half this. The most important determinations of the effect of the soil solution on the osmotic pressures of the cell saps of cultivated plants, however, are those of McCool and Miller [35]. Some of their results are presented in Table III.

TABLE III.

THE CONCENTRATION OF THE SAP OF THE ROOTS AND TOPS OF CORN GROWN IN SOILS OF DIFFERENT CONCENTRATIONS. PERIOD OF GROWTH SIXTY DAYS.

Soil.		Tops.		Roots.
Osmotic pressure atmospheres.	Moisture content, per cent.	Osmotic pressure atmospheres.	Moisture content.	Osmotic pressure atmospheres.
(a) 1·748	13·60	8·672	78·24	6·747
5·844	10·39	9·724	79·75	13·00
12·220	10·41	10·648	77·66	13·93
(b) 2·050	13·84	8·341	78·97	6·507
6·14	10·48	9·604	79·36	13·42
11·41	10·71	10·810	78·41	12·79

It will be observed that the fluctuations in the osmotic pressures of the soil solution are reproduced in both tops and roots of the maize plants. The required osmotic pressures of the soil solution were obtained by the addition of nutrient solutions to the soils, and are therefore greatly in excess of that which prevails normally in the soil.

The same investigators [52] have also presented some experiments, which appear to indicate that the osmotic pressure of the soil solution of normal non-saline agricultural soils may at times be tremendously high (Table IV). The osmotic pressures of both roots and tops, as well as the water content and freezing point lowerings* of the soil were determined at successive stages until the plants were completely wilted.

TABLE IV.

Condition of plants.	Soil.				Roots.		Tops.	
	Freezing point depression.	Osmotic pressure atmospheres.	Water content, per cent.	Freezing point depression.	Osmotic pressure.	Freezing point depression.	Osmotic pressure atmospheres.	Water content, per cent.
Excellent ...	0·070	0·844	16·22	·393	4·740	·507	6·115	87·90
Good	0·320	3·857	5·21	·470	5·664	·500	6·025	88·10
Signs of wilting	1·000	12·040	3·23	·163	5·603	·473	5·694	88·00
Badly wilted ...	†		2·13	·810	9·755	·635	7·650	86·00

†Failed to freeze.

It will be observed that the osmotic pressure of the soil solution at the wilting point of the soil is greatly in excess of the power of the roots. It would thus appear that plants may wilt in normal agricultural soils merely because the tensions transmitted from the roots to the soil solution are less than the osmotic pressure of the soil solution; that is to say, the water-absorbing power of the root cells is less than that of the osmotic pressure of the soil solution.

In another series of investigations fifty-eight different soils from ten different States were examined by McCool and Bouyoucos [5], both at high and at low moisture content. The high moisture content was that at which the absorptive power of the soil was satisfied, any additional water remaining as gravitational water. That is to say, the 'hydration' capacity of the soil was fully

*The osmotic pressure is calculated from the depression of the freezing point.

satisfied. The low moisture content represented approximately minimum water content at which solidification started readily. The osmotic pressures were determined cryoscopically, by inserting a Beckmann thermometer directly in the soil. At high moisture contents, the osmotic pressures as calculated from the depression of the freezing varied from about 0·12 atmospheres in the case of sands to approximately 0·84 atmospheres for some clay loams and clays ; while at low moisture contents it fluctuated from 1·3 atmospheres in the sands to 16·5 atmospheres in some clays. The osmotic pressure at low moisture content was not only very high, but it fluctuated considerably. It was noticed that the depression of the freezing point rose at a far greater rate than that at which the percentage of water decreased, except in quartz sands where it varied inversely with the water content. In all the other types of soil, the depression of the freezing point increased approximately in a geometric progression. These results naturally gave rise to doubts as to whether these very big depressions were really caused by the concentration of the soil solution, and not by some physical factor. For if so, they obviously do not represent the concentration of the soil solution, and do not, therefore, provide a means of calculating its osmotic pressure.

Inasmuch as pressure is known to lower the freezing point of water, it seemed possible that the freezing points obtained at the low moisture contents especially, might be due to the pressure with which the soil holds its moisture. This, however, was held to be untenable, for the following reasons.

(1) The depression was found to increase in a geometric progression as the percentage of moisture decreased in an arithmetic progression, consistently and uniformly from the highest to the lowest water content. Now if the pressure of the films influenced the depression of the freezing point, the rate of increase should not be the same, but entirely different, since the pressure of the films does not begin to be manifested until the moisture content is considerably reduced. Probably there should be rather an abrupt change in the results at the point where the water is reduced almost entirely to film water.

(2) If the pressure of the films influences the freezing-point lowering of the soils at low moisture content, it should affect it also at high moisture content, because after the free water is solidified, the remaining water exists in films just as in the low moisture content, and the effect would be more or less constant in both cases.

(3) There are abundant evidences which go to indicate that when the soil mass is sufficiently supercooled, and water begins to freeze, the physically adsorbed water freezes like free water, if it freezes at all, and the forces which hold the water do not influence the lowering of the freezing point. If pressure, or the allied forces, influence the depression at all, it is in causing some of the water in the soil to become unavailable or inactive, and thus not be in a free condition to act as a solvent, and take part in dissolving the salts of the soil.

It was concluded, therefore, that the enormous lowerings of the freezing point at low moisture contents were caused by and

represented the actual concentration of the soil solutions, and th at they therefore contradict the views held that the soil solution is very dilute.

In order to explain why the lowerings of the freezing point should increase in a geometric progression, while the percentage of water decreases in an arithmetic progression, and does not follow the direct increase ratio as might be expected, the following hypothesis was formulated.

(1) The hypothesis assumes that a portion of the water found in soils is inactive, and does not take part in dissolving the salts in the soil, and is removed from the field of action as far as the lowering of the freezing point is concerned. Under this assumption, the increase of the freezing point depression in a geometric progression as the percentage of water decreases in an arithmetic progression is explained as follows : If a clay soil, for instance, causes 15 per cent. of water to become inactive, and this clay at 39 per cent. of moisture produces a lowering of the freezing point of 0·075° C., and at 22 per cent. 0·9870° C., then at the former moisture content there is 24 per cent. of water free or available to dissolve the salts in the soil, while at the latter water content, there is only 7 per cent. available for the same purpose. It would be natural, therefore, that the depression of the freezing point would be many times greater at the low moisture content than at the high, than would be expected from the difference of the total moisture content, ust as the experimental data really indicate.

(2) The hypothesis also assumes that the percentage of inactive water is greater at the low than at the high moisture content, and tends to decrease from the former to the latter.

It will have been observed that the reasons which were held to negative the view that the great increases in the freezing points were due to the pressure with which the soil holds it moisture, are based on the assumptions that only a portion of the soil moisture is under pressure, and that this portion therefore dces not function as a solvent for the soil solutes. This 'unfree' water is supposed to exist as water of hydration and solid solution. It will be well to consider whether these assumptions can be sustained. On their validity depend not only the much debated question as to the concentration of the soil solution, but also the nature of the soil conditions which determine the wilting of plants in the normally non-saline agricultural soils.

As is generally known, a gel placed in water imbibes water and swells, but the total volume gel plus water decreases, i. e. the process is accompanied by compression. It follows on thermo-dynamic grounds that this imbibition of water is accompanied by the liberation of heat. The swelling is continuous, so that the pressure with which the gel holds its moisture must vary continuously with the amount of water.

It is also known that the vapour pressure of salt hydrates decreases by sudden steps as water is withdrawn at constant temperature, indicating that definite hydrates are being formed, whereas when hydrogels lose water, the vapour pressure decreases continuously, indicating that no definite hydrates are being formed. In the soil we may assume (Keen) [35] provisionally, that the gel-complex coats more or less completely the soil grains, especially those of smaller size. When water is

added to a dry soil, a considerable amount of heat is evolved (Bouyoucos).[6] It seems a legitimate assumption that the energy liberated is mainly due to the compression of the water imbibed by the soil gels. It would follow that this process of compression continues until the hydration capacity of the gels is satisfied. At low moisture content the pressure is enormous (Shull[64]), while it falls off rapidly as saturation is approached. There should therefore be, assuming this line of argument to be correct, no part of the soil moisture lost on drying at 100°C., which is incapable of functioning as a solvent. The only distinction between the moisture at low and high water contents is the degree of compression. The higher the compression, the greater one would expect, should be the capacity for dissolving salts.

(3) Shull[64] has measured the pressure with which the soil holds its moisture in a number of different types of soils, at various moisture contents. Using Xanthium seeds, which have almost a perfect semi-permeable membrane and rapid moisture equilibrium adjustment, he has been able to measure, by means of solutions of known osmotic pressures, the forces with which the seeds absorb moisture at any given moisture content. The seeds were in turn employed to determine the complex of moisture-holding forces of the soil. This was accomplished by introducing into the soil the air-dry seeds whose water-attracting forces were to be determined, and removing them after the attainment of equilibrium. Since the internal water-attracting forces of the seeds had been already determined at different moisture contents, the forces opposed by the soil to the absorption of water by the seeds could be calculated from the moisture contents of the seeds when in water equilibrium with the soil. The method measures, therefore, not only the surface forces with which the soil holds its moisture, but in addition, the osmotic pressure of the soil solution. The results showed that the magnitude of these forces at the wilting point of the nine soils examined was as low as four atmospheres, whereas, the freezing point method, it will be remembered, gave results as high as fifteen atmospheres for the osmotic pressure component alone. Shull also shows that the total force with which the air-dry soil holds its moisture is approximately a thousand atmospheres, but that in the neighbourhood of the wilting point, the magnitude of these forces diminishes very rapidly, the decrease being much more rapid in sand than in clay.

It may be asked then, whether pressures as low as four atmospheres afford an adequate explanation of the large depressions shown by the soil solution in the neighbourhood of the wilting point. The answer is in the negative, for it requires approximately 110 atmospheres[4] to lower the freezing point of water by 1°C. There are two facts to be remembered, however, in this connexion. The first is, that the pressure increases at an enormous rate in the region of the wilting point as the moisture content diminishes. The second is, that the separation of ice effects a reduction in the actual moisture content of the soil, and a concomitant increase in the pressure and freezing point of the liquid phase.

(4) Livingston and Koketsu[45] have recently determined the water-supplying power of a number of soils at the wilting point, by inserting small porous-porcelain cones into the soil at

the time the plants wilted. Plants of *Coleus blumei* and *Triticum sativum* were grown in twelve different soils, including a heavy loam, a sand, and a very pure humus, together with various mixtures of loam and sand, loam and humus, and sand and humus. At, or about, the critical stage of 'permanent wilting', the water-supplying power of the soil around the roots was determined. As already indicated, the imbibitional forces of porous-porcelain take no direct account of the osmotic pressure of the soil solution, whereas the plant with its semi-permeable membrane must. It will be evident then, that had considerable fluctuations existed in the osmotic pressures of the soil solutions of these soils at the time of wilting, the water-supplying powers, as determined by the rate at which water was withdrawn by the forces of imbibition of the porous-porcelain cones from the soils, would vary greatly, for the plant would wilt when the total forces of the soil in contact with the roots exceeded a definite critical value. Livingston and Koketsu showed, however, that the water-supplying power was practically the same for all the twelve soils examined. The present writer has very recently obtained results in full accord with those of Livingston and Koketsu. It will be patent then, that these investigations lend no support to the view that the osmotic pressure varies considerably from soil to soil, at the critical stage of permanent wilting.

(4) Briggs and Shantz [7] have found that the wilting coefficient of the soil could be calculated from the moisture equivalent by the following equation :—

$$\frac{\text{Moisture equivalent}}{1{\cdot}84 \pm 0{\cdot}013} = \text{wilting coefficient.}$$

The moisture equivalent of the soil is the percentage of water it can retain in opposition to a centrifugal force of one thousand times that of gravity [i.e., of approximately an atmosphere]. Any moisture retained is therefore held by the soil with a pressure in excess of one atmosphere. The wilting coefficient of the soil, on the other hand, is the percentage of water retained by the soil in contact with the roots against the forces exerted by the water-absorbing power of the root cells at the time of 'permanent wilting'. The former depends only on the surface forces with which the soil holds its moisture, whereas the latter is a function also of the osmotic pressure of the soil solution. A nearly constant relation between the two is impossible, if considerable fluctuations exist in the osmotic pressure of the soil solution of different soils at the time of wilting. Some of Briggs's and Shantz' results are reproduced in Table V. It will be observed that a nearly constant ratio does exist between the wilting coefficient and the moisture equivalent, and that therefore, considerable fluctuations in the osmotic pressures can not have obtained, in the soil solutions of the soils employed in the experiement.

It must be concluded, therefore, that the freezing point method does not serve as a reliable means of determining the osmotic pressure of the soil solution at low moisture contents. It would appear that the wilting of plants from excessive osmotic pressures in the soil solution is comparatively rare under normal agricultural conditions. It should not be forgotten, for instance, that the concentration of the soil solution is markedly diminished by the growth of the crop (Hoagland,) [32] and that as the moisture of the soil approaches the wilting point, solutes, in addition to water, are being continually removed by the plant.

TABLE V.

RELATION OF THE WILTING COEFFICIENT TO THE MOISTURE EQUIVALENT OF SOILS RANGING FROM SAND TO CLAY.

Types of soil.	Moisture equivalent.	Wilting coefficient.	Ratio of moisture equivalent to wilting coefficient.
Coarse sand ...	1·6	0·9	1·78
Fine sand ...	4·7	2·6	1·81
Sandy loam ..	9·7	4·8	2·02
Fine sandy loam	18·1	9·7	1·87
Loam	18·9	10·3	1·83
Loam	25·0	13·9	1·80
Clay loam ...	27·4	14·6	1·88
Clay loam ...	30·2	16·3	1·85

THE OSMOTIC PRESSURE OF THE CELL AS AN INDEX TO THE ARIDITY OF THE ENVIRONMENT.

The very striking manner in which the aridity of the environment, as a whole, is reflected in the osmotic pressure of the cell sap will not have escaped attention. It has been pointed out that this relationship is, within limits, independent of the nature of the aridity. The salinity of the mangrove swamp, for instance, may operate similarly to that of the surface forces of the normal agricultural soil in withholding moisture from the roots. On the other hand, high aridity of the aerial environment may also, within limits, neutralize the presence of an abundance of available moisture in the subterranean environment, and vice versa. Barrington Moore [55] has even suggested that the osmotic pressure of the plant cell might be employed as an index to the habitat. It will be readily understood that if individuals of the same strain of plant were grown in habitats of varying aridity, the osmotic pressures of their respective cell

saps might well reflect these fluctuations in the aridity of their environments more or less closely, according to the nature of the plant employed.

The Daily Water-Deficit.

It has already been pointed out that there normally occurs a water-deficit, sometimes of considerable magnitude, during the forenoon in the foliage leaves of plants. That this water-deficit in the leaves is accompanied by a corresponding augmentation in the water-absorbing power of the mesophyll cells, and a concomitant increase in the tensions in the water-columns throughout the plant body, will require no emphasis. The extent of the water-deficit and of the water-absorbing power of the leaf, and the magnitude of tensions in the water-columns of the plant are primarily functions of the daily variations in the rates of transpiration, and this in turn depends very largely on the desiccating power of the air. The leaves exposed to direct sunlight will, for this reason, tend to be depleted of their moisture to a much greater extent than those in the shade, in the interior regions of the plant. It is perhaps not always recognized how great are the fluctuations in the daily rates of transpiration in leaves in exposed situations (Livingston) [38], especially in the tropics, nor how dissimilar are the rates while the sun is up in different regions of the same plant (Harrison) [25]. There are two factors which should not be forgotten in connexion with the latter; firstly, the production through transpiration of an artificially humid atmosphere in the shaded regions of the interior of the plant; and secondly, the effect of wind and of the solar radiation absorbed by the exposed leaves.

Now tension, like hydrostatic pressure, is transmitted uniformly in all directions in a liquid. The tensions are transmitted, therefore, since water is a continuous phase, from those parts of the plant's periphery where transpiration is very active, to those regions where the rate of water-loss is smaller. When transpiration is very rapid, as it is normally during the forenoon, water may be withdrawn from one leaf to another, or it may be sucked from the buds, young fruits, or the embryonic cells of the growing regions by the augmented water-absorbing power of mesophyll cells. In fact, a water-deficit will occur not only in the rapidly transpiring cells of the leaf, but throughout the whole plant body. The factors responsible for the diurnal variations in the tensions in the water-columns and the water-deficits of the leaves have already received some consideration. It was indicated that the water-deficit in the leaf was due to the lag between the rate at which water was evaporated from the leaf peripheries, and the rate of supply from the adjacent xylem vessels, and that the latter was to some extent dependent on the water-supplying power of the soil. As the effect of the latter may not be immediately apparent, it will be well to trace briefly the effect of the daily fluctuations in the rate of transpiration on the back-pull, due to the pressure with which the soil holds its moisture at high and low moisture contents, respectively.

As the soil in immediate contact with the roots is depleted of its water, its avidity for moisture is increased, and a gradient is established between it and the adjacent soil, so that a move-

ment of water in the direction of the roots takes place. Now the back-pull depends only on the pressure in the soil moisture in immediate contact with the roots. It is the daily fluctuations in the pressure here, therefore, that have to be considered. When the pressure with which the soil, as a whole, holds its moisture is approximately zero, as it is when the soil is nearly saturated, a comparatively small gradient is sufficient, even during rapid transpiration, to ensure the necessary flow of water in the direction of the roots. Under these conditions, there occurs a relatively small diurnal increase in the pressure in the soil solution in contact with the roots, and therefore in the back-pull, when the upward pull comes on the water-columns during the forenoon. On the other hand, when the pressure is about three atmospheres, as it is when the moisture content is a little above the wilting point of the soil, in order to ensure the same rate of water-supply to the roots, a much greater augmentation in the pressure in the soil moisture in contact with the roots is needed during the forenoon. It will be patent, therefore, that the diurnal fluctuations in the back-pull due to the soil is a function not only of the desiccating power of the air, but also of the pressure with which the soil as a whole, holds its moisture. It is for this reason that the water-deficits in the plant are greater when the moisture content of the soil is low.

Serious water-deficits in the leaves may no doubt also occur, if root absorption is limited by the development of high temperatures in the soil when the sun is up, or if the oxygen supply of the roots is cut off by water-logging. Some of the consequences attending the production of large daily water-deficits in the transpiring leaves and tensions in the water-columns of the plant may now be considered.

Premature Shedding of Leaves, Fruit, Etc.

It has long been known that abnormal water relations frequently lead to the premature shedding of various parts of the plant. Thus, Balls [3] in Egypt observed that the shedding of leaves, flower-buds, or young bolls of the cotton plant was brought about by any factor which checked the absorption of water by the root. The main cause, he concluded, if not the only one, was the water content of the plant. Pruning of a few roots, for instance, was followed within four days by the complete severance of the tissue of the absciss layer; but if the plants were screened from direct sunlight, little or no shedding occurred. Harland [26] in St. Vincent noted that the shedding of both buds and bolls was heaviest after torrential rainfall. He concluded that there was a deficiency of oxygen in the water-logged soil, and that this diminished the absorption of water by the roots. Livingston and Free [43], it may be noted, have recently shown that the first effect of oxygen deprivation, is an interference with the absorption of water by the roots. The first effect of the heavy rainfall, however, would be a considerable slackening of the tensions in the water of the cotton plant, for the effects of the deficiency of oxygen would not be apparent until the soil had been water-logged for some days. Lloyd [47 48] in his work on the cause of the formation of the absciss layer in the same plant, concluded that the causative actor lay in a steady decrease in the moisture content of the soil in contact with the roots. This leads to an augmentation

in the fluctuations in the saturation-deficits of the leaves, and in the tensions in the water-columns of the plant. Lloyd, though working in the humid Southern States, makes the statement, that there seldom occurs a day on which there is no minus water-deficit in the plant.

It remained for Hodgson [33], who carried out an admirable investigation of the abnormal shedding of the young fruits of the Washington Navel orange, to throw additional light on the mechanism of the formation of the absciss layer. He found that the diurnal water-deficits in the leaves were accompanied by similar water-deficits in the young fruits. He concluded that the daily augmentation in the tensions in the watery columns led to a suction of water from the young fruits, and that these diurnal water-deficits obtaining in the fruits, furnished the stimulus for the formation of the absciss layer. In a later paper [34] the same writer gives an account of the mode of foliar abscission in Citrus. In the formation of the absciss layer, the most notable change lies in the fact that, during abscission, the walls of the abscission cells show a marked swelling and gelatinization, very similar to that caused by the action of pectose on pectic compounds. The subsequent dissolution of this wall resembles markedly the action of pectinase on pectic coagulums. MacDougal, Richards and Spoehr [51], in their paper on the basis of succulence in plants, point out that the reduction of the water content of the cell below a certain point may result in the conversion of polysaccharides, which do not show a high imbibition capacity, to pentosans, which, when mixed with nitrogenous substances, have an enormous hydration capacity. Succulence, therefore, may be a direct result of aridity. The production of the absciss layer seems to involve a somewhat similar reaction.

The production of excessive turgor pressure, though never furnishing, so far as the writer is aware, the stimulus for the formation of the absciss layer (c.f. Goodspeed and Kendal),[24] may lead to the actual rupturing of the cell walls. After a relatively dry spell, for instance, both the water-absorbing power of the plant cells and the tensions in the water columns may be comparatively high. A torrential fall of rain augments the water-supplying power of the soil, and at the same time checks transpiration. The consequent slackening in the tensions in the water-columns of the plant, permits the cells to gorge themselves with water. The turgor pressures thus produced are sometimes of sufficient magnitude, as in the Crack Neck disease of Chrysanthemums [14], actually to rupture the cell walls. In many other plants under these conditions, there is an actual exudation of water. (See Priestly [57], Miller [54], Duggar and Bonns [21].)

GROWTH.

Balls [3] found that the elongation of the stem of the cotton plant in Egypt was checked immediately the sun struck upon it, and that a slight shrinkage usually followed. A cloud passing across the sun was immediately effective, he says, in permitting growth, which ceased again directly the cloud had passed. He concluded that the loss of water was the direct cause of growth cessation.

Thoday [66] noted that the area of many leaves decreased by 2 or 3 per cent., and in some cases as much as 6 per cent.; while Krans [36] observed that even tree trunks might shrink in diameter during the day. Other investigators (Darwin [15], Smith [65]) have found the same to be true of certain fruits. It is now probably a matter of common observation, at least under arid conditions, that growth* is either retarded or ceases altogether on clear days while the sun is up. It would appear, in fact, that the plant pulsates, diminishing in volume while the sun is up, and increasing during the night; the amount of growth being a function of the excess of the latter over the former. (See Brown and Treleaze on Shrinkage and Elongation [10].) MacDougal [50], whose investigations on hydration and growth have emphasized the importance of the rôle of the cell colloids in this connexion, has pointed out that 'growth consists of two fundamental features—hydration of the colloidal material of the plasma, and the arrangement of additional material in colloidal structures, with the entailed additional capacity for absorbing water. The former might evidently occur without the latter, but the latter cannot occur without the former. Satisfied hydration capacity of the cell gels of the embryonic cells is thus apparently essential for growth. This condition, however, does not obtain while transpiration is relatively rapid, for the diurnal augmentation in the tensions of water-columns entails a suction of water by the transpiring leaves from the regions where growth occurs. The delicate balance, MacDougal says, between water-loss and absorption, as revealed by measurements of growing organs of all kinds, is very striking. The rate at which water is received is generally so little in excess of the transpiration that a rise of 10° C. to 15° C. may extinguish the balance. At the same time such a rise of temperature may result in a lessened hydration capacity, so that by the action of the acids at the higher temperature, water may theoretically be forced out of the colloidal complex.

Thermo-Regulation.

Only a relatively insignificant fraction of the radiant energy absorbed by the leaf is employed in the elaboration of corbohydrates: the major portion is dissipated in the vaporization of water. A freely transpiring leaf has seldom, for this reason, a temperature much above that of the surrounding air. If transpiration is limited for any reason, however, the temperature of the leaf may rise considerably. A correlation between tissue temperature and transpiring power might therefore be expected to exist. Investigation, indeed, indicates that thermo-regulation, due to the vaporization of water, is particularly efficient. Thus, Balls [3] states that the temperature of young cotton leaves in Egypt rarely exceeded the shade temperature, but frequently fell below it, the extreme variations being 0°C. to −6°C. In this connexion Wilcox [68] draws attention to the fact, that, as tropical plants are very sensitive to changes in temperature, rapid transpiration, due to wind, may reduce the temperature

*As measured by increase in volume: increase in dry weight due to carbon assimulation, etc., is not apparently sensibly checked as long as the stomata remain open. (F. Miller [54].)

sufficiently to kill the plant. Old leaves, on the other hand, were found by Balls rarely to fall below air temperature, but frequently to rise above, it varying from – 3°C. to + 10°C. Mrs. Shreve [62], whose work was carried out at Tucson, Airzona, has made some determinations which appear to indicate that the surface temperature of a leaf growing in the open may fluctuate by 1°C. to 3°C. within twenty to sixty seconds, and, in moderately strong winds, may change as much as 5°C. in thirty second.

AGRICULTURE.

The economic significance attending the cessation of growth during the greater part of the forenoon, and of the premature shedding of various parts of the plant need not be emphasized here. There are, however, other consequences which appear to follow in the train of a series of saturation deficits in the plant body. It has been observed, for instance, in parts of the West Indies, that where environmental conditions are not conducive to the maintenance of the water-balance, certain plants are especially liable to be attacked by insect pests As yet, it may be remarked that there appears to be no knowledge of the effect of a series of abnormal saturation deficits on the metabolic transformations, on which may well depend the immunity or the susceptibility, as the case may be, of the plant to the attacks of the parasite.* It would be premature, however, to elaborate this phase of the subject further, until the investigations at present planned have been completed.

Before concluding, the methods employed in the cultivation of crops to limit the diurnal fluctuations in the water content of the plant should be briefly considered. It will be evident that this can only be accomplished by stabilizing the tensions in the water of the body of the plant, and that both ærial and subterranean environments have consequently to be considered. The primary factor responsible for the periodic variation in the magnitude of the tensions in the water of the plant is, of course, the daily fluctuations occurring in the desiccating power of the air. Theoretically, the ærial environment could be modified in two ways in order to stabilize the tensions. Firstly, the rate of transpiration could be artificially reduced while the sun is up. This practice is adopted in the West Indies in the cultivation of tobacco, which is shaded with cheese-cloth; and in the cultivation of cacao, which is generally grown in the shade of larger trees. The growth of cover crops in orchards, and many other schemes too numerous to mention, may serve the same purpose. The second method, by means of which the tensions in the water tracts might be partially stabilized would be to augment artificially, the rate of transpiration during the night. This, however, has never been attempted in agricultural practice, though some work of Duggar and his associates opens up rather an interesting question in this connexion.

Duggar and Cooley [20] found that the application of weak Bordeaux mixture brought about a marked acceleration in the

rate of transpiration. In a more recent paper, Duggar and Bonus [21] show that the increase in the rate of transpiration occurs mainly, if not entirely, during the night intervals.

There may be little or no change, they say, during the day intervals, and to a considerable extent, at least, this is independent of slight changes in weather conditions. The explanation which appears to be wholly rational, put forward by the authors, deed not be considered here. It will be realized, however, that the effect of this increase in the rate of transpiration during the night, must tend to stabilize the tensions in the water of the plant body, and thus to check the rhythmic fluctuations in its volume. That the subterranean environment may also play an important part in bringing about abnormal saturation deficts in the plant, has been already indicated. It has been pointed out that if the absorption of water by the roots is limited for any reason, augmented fluctuations in the water content of the aerial parts must necessarily result. The use of mulches to conserve the moisture of the soil and to prevent the development of excessive temperatures during the day, and of drains to prevent the water-logging of the soil, are too well known to require elaboration.

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A NOTE ON SOME RECENT RESEARCHES ON THE COTTON PLANT IN THE WEST INDIES, WITH SPECIAL REFERENCE TO ST. VINCENT.

BY T. G. MASON, M.A., B.Sc., Agr. B.,

Botanist on the Staff of the Imperial Department of Agriculture.

In an admirable series of investigations (2), (3), (4), which were carried out in St. Vincent, Dr. S. C. Harland has made a valuable contribution to our knowledge of the factors which limit the yield of seed-cotton in the West Indies. It was realized that an analysis of these factors could only be undertaken after a study had been made of the way in which the yield was built up from day to day. The methods adopted were to a large extent those employed by Dr. Lawrence Balls[1] in Egypt. Graphical methods were extensively used, and the results subjected to statistical treatment. The degree of success obtained is due in a large measure to the way in which it has been thus possible to analyze the results of the experiments. It will greatly clarify the presentation and consideration of the work, if the subject be subdivided and dealt with as follows :—

(1) Life-history.
(2) Manurial experiments.
(3) Environment.
(4) Fungus diseases.
(5) Spacing experiments.
(6) A comparison of the experiments in St. Vincent and St. Kitts.

(1) Life-history.

Unlike the grain crops, in which every flower-bud eventually matures into an ear, the history of the flower-bud of the cotton plant is one of heavy mortality. Though the yield of cotton is determined by the number of sound bolls, yet the potential

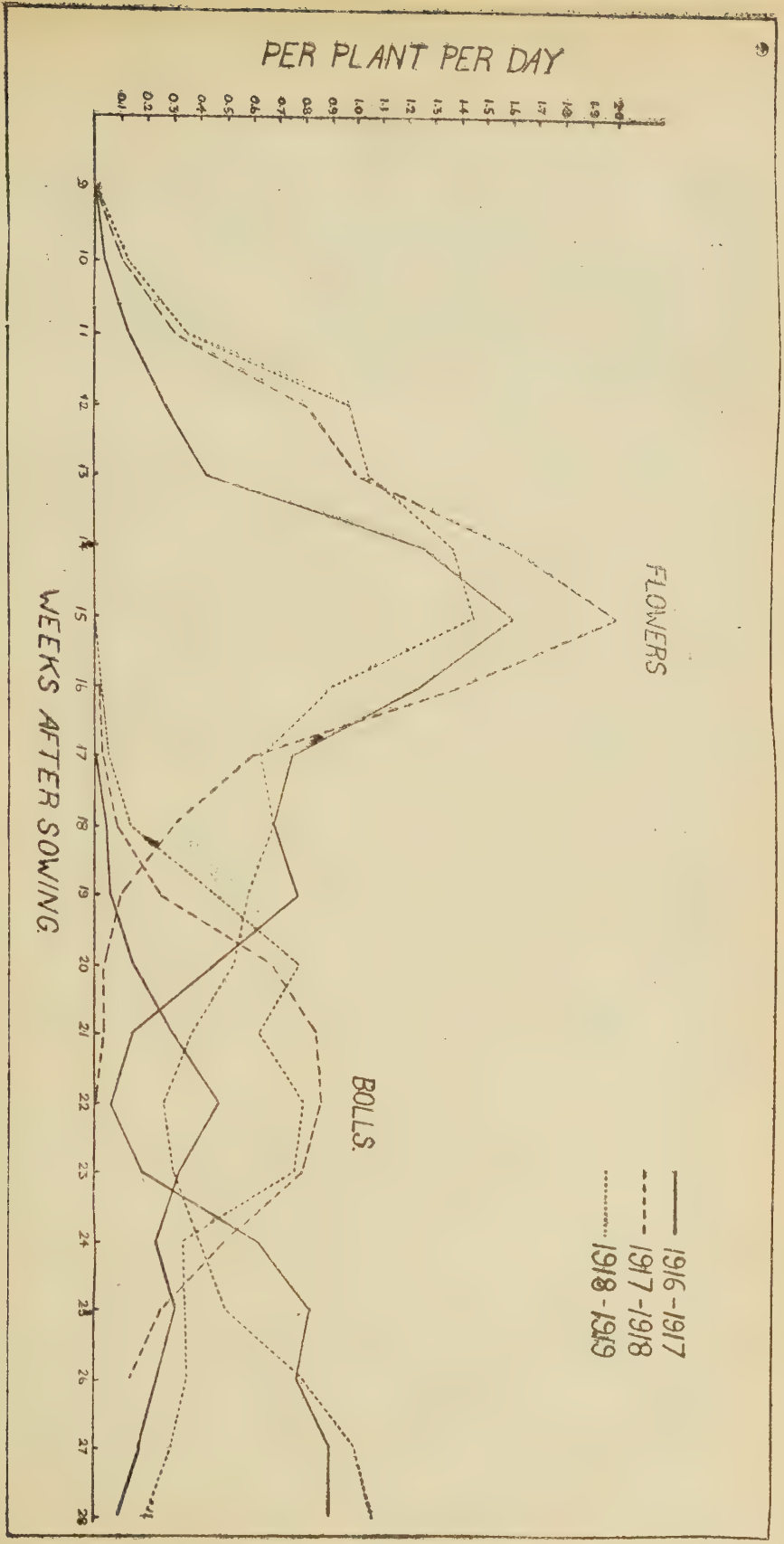


PLATE I.
Comparison of flowering and bolling curves of 1916-19.

yield is represented by the number of buds produced by the plant. In view of this, the complex of correlated factors which determine the size of the crop, can only be unravelled by tracing the boll back to its origin in the flower, and the flower in its turn to its origin in the bud. It will be patent, therefore, that there are three distinct groups of factors to be considered; the first of these controls the magnitude of the potential crop, that is to say, the number of buds produced by the plant; the second, the number of buds becoming flowers; and the third, the proportion of flowers maturing into bolls.

It was in an attempt to secure precise knowledge of the relative importance of these three groups of factors that Harland undertook to trace the life-history of the cotton plant in St. Vincent. For three seasons (1916-19) the number of flowers and bolls opening daily on each of the manurial plots was determined. The records thus obtained were presented graphically, and from them the average flowering and bolling curves for the three seasons were constructed, and are reproduced in Plate I. In the first season, that is to say, in 1916-17, this study of the rate of flower and boll production was supplemented by an intensive examination of some thirty plants, by means of which a record was obtained of the fate of every bud, flower and boll produced. As this intensive study was not repeated, it will be evident that information as to the size of the potential crop, and of the loss sustained from bud-dropping, is thus available for only a single season.

Inspection of the flowering curves of the three seasons shows that they all commenced at the end of the ninth week from sowing. The date on which the first flower appeared, however, was in every case the fifty-seventh day after sowing, but the rate of flower production was not sufficiently large to be indicated in the curve till the end of the ninth week. The uniformity of this interval is most remarkable; it will be evident that it is independent of the variations which occur in the weather from season to season, and, therefore, is in no way correlated with the factors determining the rate of vegetative growth of the plant.

TABLE I.

MANURIAL EXPERIMENTS, 1912-18.

Description of treatment.	Mean yield of seed-cotton per acre, in lb.	Per cent. gain over No manure.	Statistically significant per cent. gain over No manure.
No manure.	514	–	–
Nitrogen as sulphate of ammonia 30 lb. per acre.	607	+18	6
Phosphorus as basic slag 40 lb per acre.	607	+18	6
Potash as sulphate of potash 30 lb. per acre.	730	+42	30
Phosphorus 40 lb. potash 30 lb.	856	+28	16
Nitrogen 30 lb. phosphorus 40 lb. potash 30 lb.	639	+30	18
Cotton-seed meal 600 lb. per acre	593	+15	3
Cotton-seed meal Phosphate and Potash	733	+42	30

The striking uniformity in the dates of maximum and minimum flower production will require no emphasizing. It will be seen, however, that in 1917 the flowering curve comes to an abrupt termination, while those of the other seasons commence again to rise to another series of high values. There are thus two distinct portions of the flowering curve under normal conditions. In the first, practically all the flowers are produced on sympodia from the main axis, but after the date of maximum flower production (the end of the fourteenth week after sowing), a few flowers begin to be produced on sympodia from the vegetative branches. The second portion of the curve is composed almost entirely of flowers from the main axis. The latter portion of the curve was not traced to its conclusion, and, as a second picking is seldom obtained from it in St. Vincent, attention will be limited to the first portion.

The commencement of the bolling curve is just seven weeks later than that of the flowering curve, and a similar period separates the dates of their respective crests. This is due, of course, to the uniformity in the period required for the maturation of the boll. In St. Vincent, this is approximately seven weeks (mean period is fifty-one days). An exception to this, for which there is no adequate explanation, was found to occur in three out of the eight manurial plots in 1916-17; the interval in this case between the crests of the respective curves was only six weeks.

In estimating the number of bolls from each plot, a separation had to be made between diseased and healthy bolls. The convention adopted was to count as healthy only those which were less than half-diseased. It is necessary to bear this in mind in comparing the amplitudes of the flowering and bolling curves. The difference in their amplitudes is of course proportional to the number of flowers which failed to mature into sound bolls. In 1916-17 as much as 82·8 per cent. of the flowers failed to produce bolls; in the following season 51·8, per cent., and in last season (1918-19) 63 per cent. The factors responsible for the fluctuations in these figures will be considered in the ensuing portions of this paper. In comparing the forms taken by the two curves, a marked correspondence will often be seen between their irregularities. The fixed period for the maturation of the boll is not in itself an adequate explanation, for unless the factors determining the percentage of flowers lost had remained constant throughout the period, the distortions in the flowering curve could not have been reproduced in that of the bolling.

In addition to erecting the scaffolding on which the analysis of the various factors limiting crop production was subsequently based, this phase of the investigations has produced some extremely interesting and useful information, which as regards St. Vincent, may be summarized as follows:—

(a) If the date of sowing be known, we can state with certainty when most flowers and bolls will be produced, and when the crop will be finished.

(b) Practically 50 per cent. of the June-July planted crop may be lost through bud-shedding.

(c) During the fifty-one days of the life of the boll, the period of the greatest susceptibility to shedding occurs in the first three weeks; and, broadly speaking, it seems that if a boll is able to stay on the plant for twenty-one days, there is considerable probability that it will arrive at maturity.

(2) Manurial Experiments.

The manurial plots in St. Vincent which are permanently devoted to the experiments, are each $\frac{1}{20}$ acre; there are twenty-four plots (three series of eight), each of which receives the same treatment, year after year. The nature of the manurial treatment, and the results of the experiments for the seven year

1912-18, are reproduced in Table I. In order that the effects of variations in the seasons* during which the experiments were in progress might be eliminated, the yields obtained in the different years have been brought to a common standard by taking the annual mean of the yields of each series of plots as 100, and expressing them as percentages. By then determining the experimental error for the whole period, it was shown that the percentage gains of the manurial plots over the plot receiving no dressing could not with certainty be ascribed to the nature of the treatment, unless they were greater than 12 per cent. For convenience, the percentage gains, which may with certainty be written down to the treatment irrespective of seasonal variations in the weather, are given in the last column of Table I. Precise information as to the gain in yield which may confidently be anticipated from the application of any of the manures, or combinations of manures which have been used in the experiments, is then available. The statistical treatment of the results, however, by its very explicitness, is liable to be misleading unless its limitations are clearly recognized. In order that returns approximating to those recorded in Table I. may be obtained in places other than the experiment station where the work was carried out, it is essential that the methods of cultivation, the soil conditions, and the seasonal weather variations of the two should not be greatly dissimilar.

Turning our attention now to the results of the experiments, it is evident that the outstanding feature is the effect of potash on the yield of seed-cotton. Potash alone, it will be noticed, gave a 42-per cent. increase in yield over the no-manure plot, whereas the addition of phosphorus in the form of basic slag† depressed it by 14 per cent., and the addition of phosphate and cotton-seed meal produced the same result. No explanation of this remarkably interesting fact is offered by the writer of the paper. The dynamic aspects of manurial experiments are seldom sufficiently emphasized.

It is pointed out, however, that the disease known as Red-leaf in St. Vincent, and Rust in America, is most prevalent on the plots receiving no potash. A similar state of affairs, it should be noted, occurs in America. That this disease is one of mal-nutrition, it seems to be generally agreed. In view of its importance, it is to be hoped that further information concerning it will soon be available. In the discussion devoted to this matter, and [illegible] on the yield, [illegible] and the [illegible] seem to have received the amount of attention their importance merits. Research might conceivably show that ions other than potassium could produce equivalent effects at a smaller cost.

The paragraphs in which the writer emphasizes the seriousness of the deficiency of organic matter in St. Vincent soils,

*A dry year, for instance, might be expected unduly to favour organic manures.

†It will be noticed that superphosphate was not used in any of the combinations.

receive added force from the transition now taking place in the views of plant physiologists concerning the elements necessary for the proper nutrition of the plant. It is becoming more and more evident, that inorganic substances alone are insufficient, and that in the absence of certain organic compounds, the vigour and health of the plant cannot be maintained. Burning the old cotton plants at the end of the season without making any provision for the conservation of the organic matter must inevitably render the soil incapable of producing healthy crops of any sort. Cotton-seed meal, it will be seen, at the rate of 600lb. to the acre, is insufficient.

The evidence available concerning the effects of fertilizers on the proportion of flowers producing bolls is as yet incomplete. It may, however, be concluded provisionally, that the factors favouring a good yield are likely to produce the maximum number of bolls possible under the prevalent environmental conditions.

Manures, however, seem to have no effect whatever on the time of maturing of the crop.

(3) Environment.

A complete analysis of the effects of the environment on the yield of seed-cotton is of course impossible; it would necessitate not only a knowledge of the diurnal rates of bud production, bud loss, and boll loss, but also a daily record of all the factors which constitute the environment of the plant. It will be well, therefore, to consider for a moment how much of the requisite data for such an analysis is available. The information as to the plant is fairly complete, but owing to the paucity of the data for the environment, it can unfortunately be made use of only to a very limited extent. Records of the relative humidity and rainfall are available for the three seasons. but as the former is almost valueless as an index to the effective aridity of the aerial environment of the plant, it will be clear that any discussion attempted must necessarily be limited to tracing the relationship between the rainfall and the behaviour of the plant.

The size of the potential crop, as already pointed out, is determined by the number of buds produced by the plant, and as a knowledge of this is available for only one season (1916-17), the effect on it of seasonal variations in rainfall cannot be estimated.

As the limitations imposed by the nature of the data have now been defined, it is possible to proceed to a consideration of the effect of the rainfall on the losses sustained from the dropping of buds and bolls, respectively. The former is caused almost exclusively, as the intensive studies of the first season show, to shedding from physiological causes, while the latter is complicated by the presence of fungus diseases.

It was pointed out by Balls, that the formation of the absciss

layer, which precedes the shedding of both buds and bolls, was most probably brought about by a water-deficiency, and that naturally, this shortage prevailed whenever the loss of water by transpiration from the leaves exceeded that absorbed by the roots. Some recent investigations (5) on the premature dropping of young fruits of the Washington Navel orange have amply confirmed Balls's views. Harland's experiments indicate that the same factor is probably responsible for much of the shedding of buds and bolls in St. Vincent. It was estimated that practically 50 per cent. of the June and July planted crop was lost in 1916-17 from bud-shedding. On the assumption that the size of the potential crop did not vary greatly, and that the differences in the amplitudes of the flowering curves for the three seasons are proportional to the losses sustained from bud-shedding, it can be seen (Table II) that the shedding was least in 1917-18, and was about the same for 1916-17, and 1918-19. The rainfall for the critical period for each season will be found in Table II, and for comparison is accompanied by the percentage of flowers which failed to mature into bolls. An estimate of the percentage of buds lost in each of the seasons, based on the relative amplitudes of the flowering curves, has been made, and is reproduced in the last column of the table.

TABLE II.

Weeks after sowing.	Rainfall in inches.		
	1916-17.	1917-18.	1918-19
3-7	13·80	9·45	16·81
7-11	8·31	10·33	10·05
11-15	17·54	5·39	8·91
15-19	29·82	4.66	5·41
Total.	69·47	29·83	41·18
Per cent. flowers lost.	82·8	51·8	63
Per cent. buds lost (approximate).	50	40	50

An inspection of the figures will show that the writer's conclusion as to a general relationship between the rainfall and the amount of loss sustained from the shedding of buds and bolls has been well founded. It should again be emphasized, however,

that the loss from boll-dropping is not to be ascribed to physiological shedding alone, for a considerable fraction of it is caused by fungus diseases: internal boll disease was especially destructive in 1916-17; its ravages, however, were enormously reduced, as a result of the steps taken to abolish the cotton stainer (*Dysdercus delauneyi*), in 1917-18 and 1918-19.

The writer, however, has produced evidence of a less diffuse nature. The intensive studies of the first season (1916-17), in which a daily record was kept of the number of buds and bolls shed, have completely demonstrated that the periods of heaviest rainfall were followed by enormous shedding of both buds and bolls. The interpretation of the relationship between the intensity of the rainfall and shedding is, however, less thoroughly established. It was considered that the water-deficiency in the plant which followed the torrential downpour, was due to the check to root absorption brought about by the development of anaerobic conditions in the water-logged soil. It is by no means clear, however, that the soil solution under these conditions of rainfall does become anaerobic, and though there are a variety of possible interpretations, one notices especially that the traumatic effect of the torrential rainfall has received no consideration.

Inasmuch as the major part of the crop is lost annually through the physiological shedding of buds, and, to a lesser extent, of bolls, it is to be hoped that a remedy will shortly be found, and that the enormous losses hitherto sustained will be greatly reduced.

(4) Fungus Diseases.

Before attempting to consider the effects of specific diseases on the yield of seed-cotton, it will be necessary to endeavour to arrive at an estimate of the part played by fungus diseases as a whole, in limiting crop production. Harland has shown that as much as 50 per cent. of the yield of the June and July planted crop may be lost from the shedding of buds, but practically all of this is due to physiological causes, though a bud is, however, occasionally found to be infected by the external boll disease (*Bacterium malvacearum*). Of the remainder of the potential crop, 50-60 per cent. is lost annually from the effects of disease, and the physiological shedding of bolls. An estimate of the relative importance of these two factors cannot yet be formed.

An examination of the condition of the bolls which dropped on November 16, 1916, is of interest, and is reproduced below.

RELATION OF BOLL DISEASE TO CAUSE OF SHEDDING.

Affected by internal boll disease	64 per cent.
Affected by external boll disease	21 „ „
Healthy bolls	14·8 „ „

The balance-sheet of the potential crop will therefore be somewhat as follows:—

100 buds	50 are lost by bud-shedding 25 are lost by boll-dropping	75 per cent. lost.
	25 are healthy bolls	25 per cent. recovered.

It will therefore be clear that the loss sustained from fungus diseases, though extremely important, cannot be nearly as large a factor in reducing crop production as is the physiological shedding of buds and bolls. In view of the increasing control which has been obtained over the cotton stainer, the most destructive diseases are now the external boll disease (*Bacterium malvacaerum*), and the soft rot disease (*Phytophthora* sp.); they are both most prevalent under conditions of high humidity. Experiments are recorded, which indicate that the former cannot be controlled by spraying with Burgundy mixture.

(5) Spacing Experiments.

Balls's conclusion, that the cause of the shedding of a particular boll is due to a water-shortage for that boll led Harland to suspect that the efficiency of the flowers on the outermost nodes might be less than that of those on the inner nodes. An examination of the proportion of flowers forming bolls on the different nodes proved that his surmise was correct. It was found that the efficiency of the flowers (as determined by the percentage producing bolls) of the three inner nodes was more than twice as great as that of the later nodes. Inasmuch as the stimulus for the formation of the abscess layer is due to the diurnal suction of water from the young boll by the neighbouring leaves, which takes place whenever the moisture lost in transpiration from the foliar cells is more than that supplied by the tracheae, it is evident that the greater efficiency of the inner nodes is mainly due to the shade enjoyed by the leaves in the interior of the plant. Foliar transpiration, and therefore the suction of water from the bolls, is for this reason smaller in the neighbourhood of the inner nodes. When viewed in this light, it becomes apparent that the efficiency of the flowers will be diminished if the outer nodes are suppressed by close planting, for by this means the inner nodes become less shaded.

It was considerations of this nature which induced Harland in 1917 to undertake a series of spacing experiments, in which two plants per hole instead of the normal one were left in alternate rows. The results showed that though the efficiency of the flower per plant was not sensibly altered by this spacing, yet the number of bolls per unit area was 26 per cent. greater where the two plants per hole method had been employed. This phase of the cotton experiments is one of the greatest interest, and seems to suggest that results of the utmost significance may be achieved by investigations conducted along these lines.

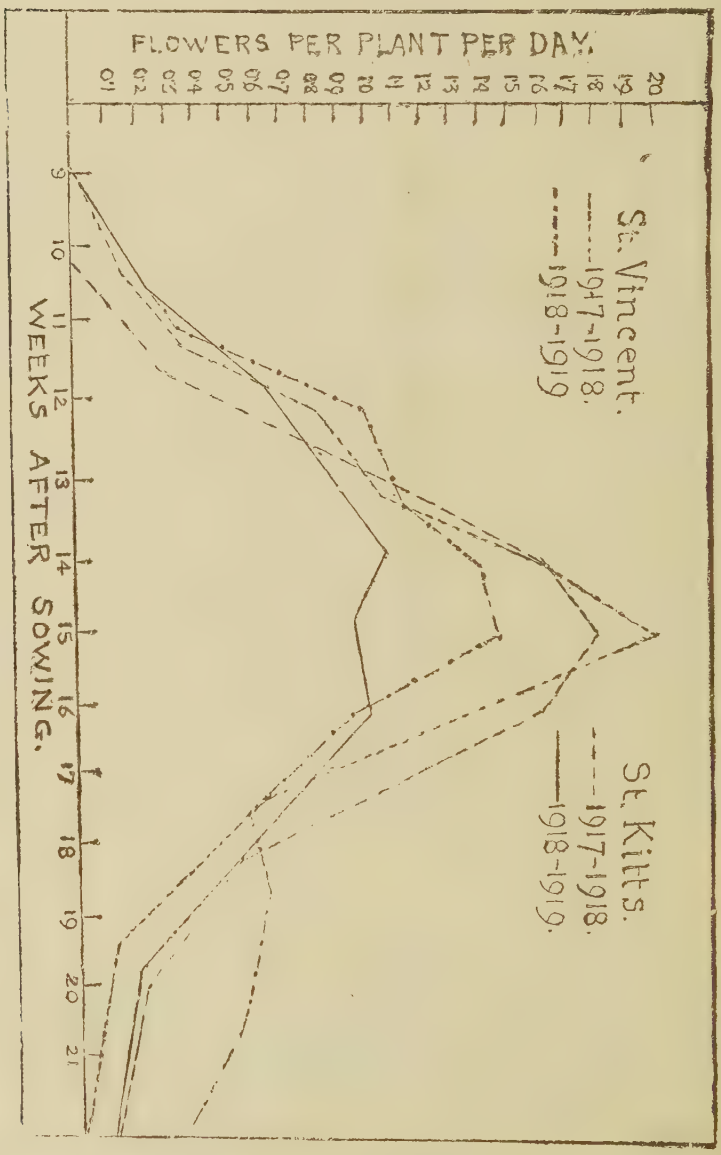
(6) A Comparison of the Experiments in St. Kitts and St. Vincent.

(A) Manurial experiments have now been in operation in St. Kitts for some seventeen years, and have been conducted by Mr. F. R. Shepherd, on lines very similar to those in St. Vincent. The results of these experiments, however, are of an entirely different nature. In St. Kitts, the maximum gain * of the mean

* This was obtained on the plots receiving a complete dressing of fertilizers.

yield of the manurial plots for the fourteen years 1904-17, is only 13·6 per cent. greater than that of the plot receiving no dressing, whereas in St. Vincent, it will be remembered, 30 lb. of potash per acre gave an increase of 42 per cent. for the seven years 1903-18. Inasmuch as there is li tle doubt that a gain of 13·6 per cent. is statistically significant for the St. Kitts experiments, it would appear that the application of fertilizers has benefited the growth of the plant to some, even if it be to a very limited, extent. Mr. Shepherd points out, however, that there are

PLATE 2.



Flowering curves, St. Vincent and St Kitts, 1917-18 and 1918-19.

indications that the effects of the fertilizers are now beginning to be more largely felt. Any explanation of the discordant results obtained in the two islands is of course impossible until their respective soils have been submitted to a biological and physico-chemical analysis.

(B) As Balls's methods were not introduced into St. Kitts till 1917, the flowering curves for 1917-18 and 1918-19 alone are available for comparison, and will be found reproduced on Plate 2. The similarity in the form of the curves in the two islands is very striking; it will be seen that the nature of the periodicity shown by the plant in St. Vincent is independent of the differences in the environments of the two islands. The mean period for the maturation of the boll in St. Kitts, however, is apparently one day less than in St. Vincent. In spite, however, of minor divergencies of this nature, it will be seen that the resemblance between the life-history of the plant in the two islands is very marked. St. Kitts, it may be mentioned, is approximately 4° north of St. Vincent.

TABLE III

Season.	Island.	Inches rainfall 3rd to 19th week after sowing.	Per cent. bolls to flowers.
1917-18.	St. Kitts.	20	63
	St. Vincent.	25	50
1918-19.	St Kitts.	13	50
	St. Vincent.	40	37

(C) ENVIRONMENT. Precise data as to the amount of loss sustained from bud-shedding is not available for St. Kitts. For purposes of comparison, however, an estimate can be obtained as follows. It will have been noticed that the ratios of the losses from bud and boll-dropping in St. Vincent for the three seasons were not greatly dissimilar; in other words, the factors which determine bud-shedding are also largely responsible for the losses sustained from the dropping of bolls. Thus, torrential rainfall was accompanied by heavy loss from both of these causes. On the assumption, then, that the percentage of bolls to flowers may be taken as an approximation to the amount of bud-shedding, it is patent (Table III) that the loss from the latter is much greater in St. Vincent than in St. Kitts. It will also be seen (Plate 2) that the number of flowers is not greatly dissimilar in the two islands (1918-19 was a very exceptional year in St. Kitts). From these considerations it becomes apparent that the productivity* of the plant, as measured by the number of buds produced, must be somewhat greater in St. Vincent than in St. Kitts.

In St. Kitts, the most potent factor determining the loss from physiological shedding of buds and bolls is evidently environmental aridity, whereas in St. Vincent, it is the reverse. Mr. Shepherd, however, points out, that in St. Kitts too, the torrential rains are followed by heavy shedding; he attributes the water-deficiency in the plant, however, to a check in root absorption, due not to the development of anaerobic conditions in the soil solution, but to the chilling effects of rain. He appears to consider also, that a sudden change in atmospheric temperature may in itself furnish the necessary stimulus for the initation of the absciss layer. It will be evident that the major part of the potential crop is lost in both islands through the physiological shedding of buds and bolls.

The explanation of the differences in the amount of shedding in the two islands is not apparent. It may be that the strain of Sea Island cotton grown in St. Kitts is less susceptible to shedding; and again, it may be entirely a question of the environment.

CONCLUSION.

It may be of interest to summarize the factors which appear to be responsible for the much greater yield of seed-cotton obtained in St. Kitts, which may exceed that obtained in St. Vincent by as much as 60 per cent. in a normal year.

i. Unlike St. Vincent, a second picking is frequently obtained in St. Kitts.

ii. The loss from bud- and boll dropping is much greater in St. Vincent than in St. Kitts.

iii. The loss from disease is relatively small in St. Kitts.

iv. Another factor, which may be partially responsible, is the density of the spacing. In St Kitts there are 5,300, whereas in St. Vincent there are only 4,356 plants to the acre.

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*This does not show, however, that the intrinsic productivity of cotton is greater in St. Vincent than in St. Kitts, for apart from differences in environmental factors, the spacing is denser in St. Kitts.

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MOSAIC DISEASES OF PLANTS.

BY MISS E. M. WAKEFIELD, F.L.S.,

Acting Mycologist
on the Staff of the Imperial Department of Agriculture.

That plants, like animals, are subject to definite diseases, has been recognized from the earliest times, and in the case of affections so important to man as, for instance, 'rust' of wheat, it was natural that there should be much speculation as to the nature and cause of disease. The earliest writers adopted either entirely superstitious views, or attributed plant diseases to definite environmental factors, as drying winds, unfavourable soil, and so on. Even when later the constant association of certain fungi with disease was noted, these were not recognized as entities, but were regarded as special manifestations of the diseased condition—products of the changed sap of the plant.

With the researches of De Bary and others in the latter part of the nineteenth century on the parasitism of fungi, there began a new era in the study of plant pathology. The fungi connected with many diseases were identified, their life-histories studied, and the causal relationships established by means of pure culture methods and infection experiments. Later, many other diseases were shown to be similarly caused by bacteria. There still, however, remained a number of affections which could not be attributed to any known organism. These have been classed under the term 'physiological diseases'. A critical examination of our knowledge as to these diseases reveals the fact, as R. E.

Smith [1] has pointed out, that they are a heterogeneous collection of phenomena, agreeing in nothing except that their cause is not known. The further conception that the diseased condition is the manifestation of some functional or metabolic disturbance, is purely an assumption. Certain diseases, at one time thought to be 'physiological', have since been proved to be connected with parasitic organisms.

Within the past thirty years much literature has accumulated on the subject of one group of these so-called physiological diseases, which have certain features in common. While no recognizable organism has been found, the symptoms are entirely those of attack by a parasite, and there is a strong body of opinion inclining to the belief that there may be involved an ultra-microscopic parasite—a conception which has already been adopted in animal pathology.

These are the mosaic diseases, so-called because the most usual and conspicuous symptoms is a mottling effect on the leaves of diseased plants, caused by the presence of irregular lighter green areas mingled with the general green groundwork of the leaf.

Mosaic diseases provide an exact parallel with certain animal diseases, such as small-pox and infantile paralysis, which are regarded as being caused by ultra-microscopic organisms. They are more or less readily communicable, and the sap of diseased plants can be filtered through ordinary bacteria-proof filters without losing its infectious properties. Furthermore, the disease is frequently transmitted to healthy plants through the agency of insects, such as aphides, which infest them (cfe. Rands and Pierce.). [29]

The best known and most thoroughly investigated of the mosaics is that of tobacco. Tobacco mosaic manifests itself in various ways. The plant may show partial or complete chlorosis, or may be entirely dwarfed. In other cases, the leaves show curling, dwarfing, blistering and distortion, or a mottling with different shades of green. The flowers may also be distorted, and in *Nicotiana tabacum*, the normally pink flowers become entirely bleached or blotched with white.

The closest search has failed to reveal any recognizable organism to which the disease could be attributed, yet it has been shown to be highly contagious. The disease may be communicated to a healthy plant by rubbing the leaves with juice from a diseased plant, or by merely rubbing with the finger, after dipping them in infected juice. The infectious principle is not removed by filtration through ordinary, bacteria-proof filters, but Allard succeeded in removing it by means of a Livingston atmometer porous cup. At the same time the filtrate showed an intense peroxidase reaction, thus indicating that the infective principle is not an enzyme of this nature.

The properties of the virus of tobacco mosaic have been investigated in some detail by Allard [2,3,4,5,6]. It remains equally infective at a dilution of 1 part of virus in 1,000 parts of water, though at greater dilutions the infective power is impaired. In such dilute solutions, the peroxidases give no

discernible reaction. The enzymes present in a healthy plant, on the other hand, can be brought to a high degree of concentration, and yet never acquire infectious properties.

The virus is markedly resistant to solutions of various salts, antiseptics, etc., unless these are very concentrated. Of all the substances tried, only formaldehyde, and alcohol stronger than 50 per cent. were found to destroy the infective principle easily. It is quickly killed at temperatures near the boiling point of water, but is more resistant when dried, and is very resistant to low temperatures, surviving exposure for fifteen minutes even to—180° C.

As already mentioned, tobacco mosaic is easily transmitted in the course of handling the plants, and it has also been shown that in nature, certain aphides are instrumental in spreading the disease from plant to plant. Infection is, however, not carried through the seed. While the virus has been shown to be present in every other part of the plant, even in the trichomes, it is absent from the embryo, and if seed is produced by a mosaic tobacco plant, the seedlings remain healthy unless infected from outside. The same holds for certain other mosaic diseases as spinach blight, and possibly tomato mosaic, though in this latter case the evidence is conflicting. In cucumber and bean mosaic, however, seed transmission takes place.

The virus from tobacco will also produce a similar disease in certain other solanaceous plants, as tomato and petunia. It has been shown by Nishimura [7] that *Physalus alkekengi* may act as a carrier of the mosaic of Solanaceae, without itself showing any symptoms of disease. This possibility of 'carriers' has to be borne in mind when dealing with supposedly immune varieties of plants susceptible to mosaic. The mottling disease of sugar-cane was probably introduced into Argentina by resistant varieties showing little sign of infection (Earle.)[8]

Within recent years, it has been shown that the disease of potatoes known as 'leaf-curl,' 'curly-dwarf,' or mosaic is also of an infectious nature, and is caused by a virus in which no visible organism can be detected. Although infection of potato can be obtained from tomato by grafting, it has not been possible to transmit the disease from tobacco. Artificial transmission of leaf-curl is not so easy as in the case of tobacco mosaic, but may be effected by certain methods, as by rubbing together leaves of diseased and healthy plants. It has been found also that infection may take place in nature by root contact (Quanjer). [24]

A second potato disease, known as leaf-roll, is also contagious, but is apparently distinct from potato mosaic. Leaf-roll is characterized by necrosis of the phlœm, causing stoppage in the translocation of starch from the leaves. Both diseases are transmitted by the tubers and from plant to plant through the roots. Mosaic or leaf-curl has been found also to be transmitted by certain aphides.

Outside the Solanaceae, mosaic diseases are known in many other cases: amongst others, *Phytolacca decandra*, sugar-beet (curly-top), spinach (blight), cucumber, sweet pea, bean

and other Papilionaceae, beet and sugar-cane. All of these are characterized by the presence of more or less mottling or distortion of the leaves, and in most cases, transmission by insects has been proved.

Insect transmission of the disease has been perhaps most thoroughly investigated in the case of curly-top of sugar-beet. This disease was shown by E. D. Ball [11] and Shaw [12] to be communicated by the beet leaf-hopper (*Eutettix tenella*, Baker). The question has been tested experimentally by numerous investigators, and it has been shown conclusively, that the leaf-hoppers are not in themselves infective, but only become so after feeding on diseased plants. No more than three hours' feeding is necessary for the leaf-hopper to obtain the infective principle, but an incubation period of forty-eight hours, or possibly only twenty-four, is necessary before the insect can induce the disease (Smith and Boncquet). [13]. This latter fact suggests that some development takes place within the body of the insect. To induce the disease in a healthy beet, it is sufficient to confine one virulent leaf-hopper for five minutes on a leaf of the plant. Of great importance in connexion with the perpetuation of the disease from season to season, is the fact shown by Boncquet and Stahl [14], and by Carsner [15], that various wild plants are susceptible to the virus, and further, that leaf-hoppers may retain their virulence for a long time, even when feeding on non-infected plants. Carsner considers it highly probable that overwintering of the virus is accomplished by these two factors.

Cucumber mosaic has also been communicated to various plants of the same family, including the wild cucumber (*Micrampelos lobata*). In the latter plant occasional transmission of the disease through the seed has been observed, [16] but seed transmission appears to be the exception rather than the rule in mosaic disease in general. Bean mosaic, however, appears to be carried by the seed, and is not readily communicated from plant to plant. In this case high temperatures and great humidity are found to favour infection.

The case of spinach-blight is interesting. This disease is carried by aphides, and McClintock and Smith [17] have shown that the infectious principle may be transmitted from the parent aphides to their offspring, through a period sufficiently long to tide over the interval between successive spinach crops. A similar inheritance of the virus is known in the case of some animal diseases.

At the present time interest is centred in sugar-cane mosaic, owing to its rapid spread in the West Indies, and the losses caused by it. The disease has been known in Java since 1892, although its infectious character was not then recognized. It was first noted in Porto Rico about the middle of 1916, when only a small area was affected. By 1919, more than three-fourths of the cane-fields of the islands were involved, and the disease had appeared also in Santo Domingo, Cuba, and St. Croix. In the present year it has been causing trouble in Jamaica [18] and Trinidad, [19] and has recently appeared in Barbados.

The disease manifests itself first in a mottling of the whole of the leaf with pale-green to whitish streaks and spots. The pattern varies in different varieties of cane, and may be constant and characteristic in some kinds. Spots caused by other agencies are sometimes liable to be confused with mosaic, but the latter is generally recognizable by the pale-green, not yellow, colour of the blotches, their linear shape, and occurrence over the whole surface of even the youngest leaves.

In plant canes originating from diseased cuttings, all the leaves are affected, and in the second and third years there may be a further development on both leaves and stem of white, opaque patches. The occurrence of internal lesions in diseased stems has also been recently recorded. (Matz) [25]: the effects of the disease are cumulative. Diseased canes weigh less than healthy canes, and a considerable reduction in yield is the result. Except when the stem becomes cracked, however, the sugar content of the juice is not materially affected.

In addition to primary infection through the use of diseased seed-pieces, the rapid spread of the disease early gave indication that secondary infection takes place in nature. The growing point is infected, and all leaves formed subsequently, show the mottled effect. If the infection occurs late, only the upper part of the cane shows disease, and the lower joints may give rise to sound plants or ratoons. Healthy shoots from diseased stools, when used as seed, similarly give rise to healthy plants. In this respect the virus of sugar cane mosaic differs from that of tobacco, which penetrates to all parts of the plant wherever it may be introduced.

It has not been easy to prove experimentally the infectious nature of the virus of sugar-cane mosaic, but Brandes [21] has shown that the disease may be transmitted by the corn aphis. It is unlikely that this insect is the only agent acting under natural conditions, but so far, experiments with other insects have given no conclusive results. While all the observed facts point to insect transmission, the case remains not proved.

Unlike tobacco mosaic, the sugar-cane disease can only be transmitted artificially with difficulty, under conditions at present not understood. Brandes [21] was successful only when he injected ½c.c. of the virus into the growing-point by means of a hypodermic syringe. It is perhaps worthy of note that he obtained better results with virus which had been pressed out form the shoot under oil, and thus remained unoxidized, than with virus obtained by trituration of young leaves. A repetition of this method by Earle [10] in Porto Rico, gave in one case five infections out of ten, but in two duplicate experiments no positive results were obtained. Tests of other methods of infection similarly show no uniformity, and there is evidently some factor in operation which is not at present understood.

Quanjer, [23] in connexion with phlœm-necrosis of potato, has suggested the possible action of unicellular organisms. The behaviour of the virus of sugar-cane mosaic seems to lend some support to this idea, but further experiments are necessary before any conclusions can be drawn.

In a recent publication, Matz [25] describes a plugging of the parenchyma cells in diseased leaves and stalks by a dense, plasma-like substance, with a tendency to break up later into small motile granules. The observation seems to provide at least a histological basis for the disease.

More than 1,900 varieties of cane are known to be subject to mosaic, and the list includes practically all of those which are commercially esteemed. The Otaheite or Bourbon cane is very severely injured, while Rayada, Crystalina and Yellow Caledonia also suffer badly. Louisiana, Barbados, Demerara, as well as Trinidad and other seedlings are attacked, though in varying degrees. In fact, few varieties appear to be immune, but slender canes of the North India type, generally known as Japanese canes, are said by Brandes [20] to be resistant under Louisiana conditions. The variety Kavangire, or Uba, has never been observed to show signs of disease.

One of the most disquieting features of the disease, complicating the question of control, is the fact that other cultivated and wild grasses have been found to be susceptible. The mosaic disease of sugar-cane has been proved to be transmissible to maize, sorghum, crab grass (*Syntherisma sanguinalis*), foxtail (*Chaetochoa lutescens*), and *Panicum dichotomiflorum*. A similar disease has also been observed on rice and millet (*Panicum crusgatti*, Major) in Porto Rico (Brandes) [20], [22].

The only satisfactory method of controlling the disease is by seed-piece selection, and eradication. It is transmitted by the use of diseased seed-pieces, and neither disinfection of the seed nor soil treatment has any beneficial effect. Infection is not carried by the soil.

Earle [9] has recorded the promising results of eradication experiments in Porto Rico. In the first place, only healthy cuttings should be planted. Then, when the young cane is about a foot high, the field is inspected, and all plants showing signs of disease are pulled out. This inspection and roguing is repeated at intervals of ten days, until no more cases are found.

Brandes [20] recommends roguing only when the amount of infection in the young canes does not exceed 20 per cent., or in half-grown to mature canes, 5 per cent. The size of the field and the condition of the surrounding fields must also be taken into consideration. It is suggested that as soon as all the plants have sprouted, the fields should be inspected, and all diseased stools pulled out and cast between the rows. A second inspection after a lapse of twenty-five to thirty days will show whether secondary infection is taking place. If so, the fields should be rogued as before, and a third inspection made again after the same interval, twenty-five to thirty days. It may be necessary to repeat the process several times.

In large, badly infested fields, roguing is impracticable. In such cases, Brandes suggests that the crop should be allowed to mature, every stalk ground, and the stubble ploughed up and killed. Replanting should be done with carefully selected cuttings. As a precautionary measure, some crop other than a grass might be grown on the land for a year.

Naturally the success of this method depends on its being carried out thoroughly throughout the infected region. As already indicated, the discovery of other hosts has complicated the problem. The disease is perpetuated in perennial grasses, and the destruction of all affected host-plants is practically impossible. When once the planter realizes the seriousness of the situation, however, much can be done to minimise losses by thorough roguing methods. Unfortunately, the substitution of immune varieties does not at present offer any immediate solution, for in the case of both cane and corn, the susceptible varieties happen to be the most esteemed.

It may be mentioned in passing, that Brandes [22] has observed several cases of apparent recovery from mosaic in the case of maize, crab-grass, and foxtail. He also states that occasionally, suckers from diseased stools of sugar-cane and sorghum have been observed to come up with no sign of mosaic. Inoculation experiments only will decide whether in such cases the virus is really absent, or only inactive. Brierley, [26] however, has recorded a case of what appears to be true recovery from mosaic disease of tomato. Freiberg [27] has attempted to explain it on the basis of temperature relations, but this explanation does not quite cover the facts. All these occasional records of recovery are at present unexplained.

There are a certain number of other obscure diseases of plants, which while not agreeing with the true mosaics in their symptoms, yet appear to be transmissible, and caused by an infectious virus. Among these may be mentioned such diseases as peach 'yellows', 'sereh disease' of sugar-cane, 'spike disease' of sandal, etc. In most of these cases the information yet available is scanty.

With regard to the nature of the 'virus' causing these various diseases, the theory first advocated, and still held by many workers, is that the infective principle is an enzyme. Allard's experiments proved conclusively, that at least it was not an oxidase, for he was able to show that the infective principle and the oxidizing enzymes react independently.

Freiberg [27] has since confirmed this result, but he adheres to the enzymic theory, supposing that the substance in question is of the nature of an aldehydase. Having found that carbohydrates are more abundant in the dark-green than in the light-green areas of the leaf, he connects this with the fact that formaldehyde is probably one of the first products of photosynthesis. Thus he explains the fact that Allard found the infective principle was destroyed by formaldehyde, as due to a specific chemical reaction with the formaldehyde, and not to its antiseptic properties.

The behaviour of the virus of mosaic disease of tobacco with respect to high and low temperatures, and various antiseptic solutions is certainly more in accord with that of an enzyme than with that of any organism at present known.

On the other hand, the great objection to the enzyme theory appears to be the difficulty of explaining how such a catalyst would originate. If one adopts this view, it is necessary to assume that at some period an enzyme, or a substance capable

of activating enzymes, has arisen in the plant *de novo*—possibly, as Freiberg suggests, in consequence of some disturbance in metabolism. Were this the case, it should be possible to induce the disease at any time, by engendering such a disturbance in the activities of the plant cell. As far as experiments have gone at present, however, we know of no means of producing mosaic disease in a healthy plant, except by infection from another diseased plant.

On the other hand, none of the properties of the virus so far investigated is entirely inconsistent with the theory of the presence of an organism. In particular, the fact that the virus remains active, even in extreme dilution, and is capable of increasing indefinitely within the tissues of the host, points to the action of a living organism rather than of a chemical substance. Freiberg's observations as to the existence of a maximum, optimum, and minimum temperature for the manifestation of mosaic disease are equally in accordance with the view that a parasite is present.

Until comparatively recently, the conception of such ultramicroscopic organisms remained entirely theoretical. The work of Löhnis and Smith[28] in 1916, however, on the life-cycles of bacteria, opened up entirely new possibilities in connexion with this as well as certain other pathological problems. Löhnis and Smith found that bacteria may enter an amorphous 'symplastic' stage, in which condition parasitic species might not be readily distinguishable from the protoplasm of the host cell in which they occur. Furthermore, they observed the formation of filterable 'gonidia', which may produce new bacteria directly, or after having entered the symplastic stage. In view of these facts, the possibility that eventually many of the infectious filterable viruses will be proved to contain living organisms, is brought appreciably nearer.

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THE INTERPRETATION OF RESULTS OF AGRICULTURAL EXPERIMENTS.

BY F. HARDY,

Chemist on the Staff of the Imperial Department of Agriculture for the West Indies.

Agricultural experiments (such as plot trials for estimating the effect on a crop of different kinds of manures, trials for comparing the relative values of botanical varieties of certain plants, etc.) involve errors of two sorts, i.e.—

(A) *Plot errors*, or more accurately errors due to *environmental heterogeneity*, such as lack of uniformity in soil conditions[10*] and in the subaerial conditions to which the plants growing on the plots are subjected; prevalence of insect pests and fungus diseases; and variations in the individuality of the plants.

(B) *Seasonal errors* due to *cyclic environmental factors*, of which the chief are climatic variations especially in connexion with rainfall; errors due to the personal equations of the operators who are responsible for the tillage, manuring and planting of the plots from year to year; and errors due to the fact that pure strains of the plants grown in the experiments are usually not definitely selected, so that seasonal variations in plant individuality may occur.

All these factors are interrelated, and they may together be classed as *subsidiary factors*, to distinguish them from the factor which it is the object of the experiment especially to investigate.

It is impossible to control all the factors mentioned in carrying out an extensive and long-continued series of plot trials, but wherever possible, agricultural experiments should be performed in such a way that the effects of subsidiary factors are reduced to a minimum. For example, soil heterogeneity can seldom be corrected by preliminary tillage and manuring, but care can be exercised in the choice of a site on which to lay out the plot trials, so that the greatest possible uniformity in soil conditions is obtained for the plots. The prevalence of pests and diseases cannot always be controlled, nevertheless care can be taken to use land free from specific insects and fungi likely to infest the plants subsequently to be grown, and also promptly to control any outbreak that might occur. The use of pure strains in manurial experiments is a factor of importance which is often overlooked. A heterogeneous collection of individuals of different strains is likely to affect the yield results, not only in any one growth season with annual plants, but more especially in two consecutive seasons in which annual plants of two different generations are propagated. Seasonal errors due to inaccuracy in the cultural operations, to the improper application of manures in manurial experiments, and to lack of uniformity in the method of planting, may be minimised to some extent by the employment of well-trained and painstaking field workers, and by vigilant supervision of an expert agricultural

*Reference is made by number to literature drawn up at the end of the article (p. 222).

technologist. Frequently, insufficient attention is paid in manurial experiments to the use of uniformly graded manures from one season to another. Chemical control should be exercised in this matter wherever possible.

When every care has been taken to reduce the errors due to subsidiary factors, and when the plots have been planned and laid out in the best possible way in the light of modern knowledge [3], the results obtained by plot trials must be interpreted mathematically so that trustworthy conclusions can be drawn from them.

To illustrate the methods used in the interpretation of agricultural experiments, the figures quoted in Dr. Harland's paper on Manurial Experiments with Cotton in St Vincent (*West Indian Bulletin*, Vol. XVIII, Table I, p. 31) may be used.

I. The Probable Error of a Single Result. (E_1).

The *no-manure plots* 1a, 1b, and 1c, were chosen and prepared so as to be reasonably similar with regard to plot errors as defined above In any one year the yields of seed-cotton in pounds per acre differed somewhat for the three plots, because of the effects of plot errors, but, on the whole, these differences were not very great. The differences in yield for any one plot in different years are due to seasonal errors, and these may be very marked, as for example, the decrease in yield for the year 1916, which year was an exceptionally dry one at the experiment station.

The advantage of laying out three plots for each yearly trial is obvious, therefore, because it tends to cause the mean result more nearly to approximate to the exact figure which represents the productivity of unmanured soil under the conditions obtaining at the St. Vincent Experiment Station.

Consider now the yields of the no-manure plots throughout the years 1912 to 1918. We may arrange the figures in order of magnitude, and in four columns, thus : –

220	392	521	592
242	459	528	606
248	459	529	724
352	463	560	735
375	476	578	789
			[943]

In order to have four similar columns of figures, let us ignore the last result, 943. The yield variation now lies between 220lb. and 789lb. of seed-cotton per acre. As previously stated, the combined effects of plot errors and seasonal errors are responsible for this great range of variation. The mean result of the yields is 492lb, and it will be seen that the two middle columns contain half of the results, and that these lie within the limits 492 ± 100 (i.e. 592 and 392).

Hence it is even chances for or against any single result falling inside or outside the limits of 100 on either side of the mean, 492.

The figure 100 is called *the probable error of a single result* in the series of trials under consideration.

Mathematically, the probable error of a single result can be found more conveniently by applying the formula :—

$$E_1 = \pm 0{\cdot}67 \sqrt{\frac{\Sigma d^2}{(n-1)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where Σd^2 = the sum of the squares of the differences between each result and the mean.

n = the number of results.

Calculated from this formula, the probable error of a single result of the no-manure trials is—

$$E_1 = \pm 0{\cdot}67 \sqrt{\frac{484{,}495}{(20-1)}} \quad \text{(for twenty results)}$$

$$= \pm 0{\cdot}67 \sqrt{25\,500}$$
$$= \pm 0{\cdot}67 \times 159{\cdot}7$$
$$= \pm 106{\cdot}9 \text{ lb. of seed-cotton.}$$

This figure does not differ appreciably from the figure 100 as obtained by inspection.

Expressed as a percentage of the mean (492), E_1 becomes ±21·8 per cent.

If we include the last figure (913) in the list of results for the no-manure trials as given in Harland's paper, we shall find by a similar calculation to the above that—

$$E_1 = \pm 0{\cdot}67 \sqrt{\frac{676{,}434}{(21-1)}} \quad \text{(for twenty-one results)}$$

$$= \pm 0{\cdot}67 \sqrt{33{,}821{\cdot}7}$$
$$= \pm 0{\cdot}67 \times 181{\cdot}0$$
$$= \pm 123{\cdot}3 \text{ lb. of seed-cotton.}$$
$$= \pm 23{\cdot}9 \text{ per cent. of the mean 514.}$$

Theoretically, the probable error of a single result should be, on the average, the same whether calculated from a few results or from a great number of results, for every additional observation, besides adding one unit to 'n' in the denominator of the fraction, also adds a 'd' to the numerator.

The value obtained for the probable error of a single result (± 23·8 per cent.), was derived from seven years' figures of the yields of a triad of plots, and includes errors due both to plot variations and also to seasonal climatic variations.

Dr. Harland's figure for the probable error of a single result is ± 5·3 per cent. (*West Indian Bulletin*, Vol XVIII p. 21). It is considerably lower than our estimation, for it was obtained by an averaging method which eliminates a good deal of chance

variation due to such factors as plant individuality and disease. It would be advisable therefore to understand how Harland's figure is obtained. Consider first the yield figures of the no-manure plots 1a, 1b, and 1c (*loc cit.* p. 31). Add together separately in horizontal rows, the figures for each plot for the seven-year period. The totals 3,853, 3,614, and 3,333 are obtained. Take the average of these; it is 3,600. Express this average as 100, and reduce the figures to percentages of this. The values 107, 100 and 93 are thus obtained.

Similarly work out the percentage figures for the nitrogen plots. They are found to be 86, 104 and 110. By adopting the same average of 100 in the two cases, no-manure plots and nitrogen plots, the effect of the manurial treatment is eliminated. Proceeding in the same way with the sets of plots receiving other manures, a total of twenty-four percentage figures is obtained. The formula may now be applied to obtain a value for the probable error of a single result, and the figure thus derived will be a far more reliable estimate of the probable error than our figure of ± 23·9 per cent.

We may tentatively accept Harland's value, ± 5·3 per cent, for the probable error of a single result of manurial experiments with cotton at the St. Vincent Experiment Station.

Note 1. From the results of a great many experiments on the effect of manures on the yield of cereal crops and of roots carried out in England, it has been estimated that the probable error of a single result in such experiments is approximately ± 5 per cent. [4].

2. In the Leeward Islands, Sir Francis Watts has estimated that the probable error of a single result in manurial experiments with the sugar-cane is about ± 8 per cent.

II. The Probable Error of a Mean. ($E_{m.}$).

In the example quoted in the last section, the mean 514 lb. was derived from twenty one results. Had the no-manure trials been duplicated, so that a *second set* of twenty one results had been available, then the chances are that the mean of this second set of results would have been found to be, not 514, but some other figure near to this, and either greater or less than 514. Hence for any one set of twenty-one results, the mean would differ somewhat from 514, and it follows, therefore, that there is a probability of error attached to the figure 514 as representing the mean yield of twenty-one no-manure trials for cotton at the St. Vincent Experiment Station.

The probable error of a mean implies that *it is even chance for or against that mean falling inside or outside the limits of the probable error.*

Let us suppose that each set of no-manure trials had included 500 results instead of twenty-one. The mean of *any one set* of this greater number of results would now be expected to approximate much more closely to a constant number than in the case of sets of twenty-one results. In other words, the probable error of the mean of any one set of 500 results would be expected to be smaller than that of the mean of a set of twenty-one results.

Mathematically it can be shown that the probable error of the mean of a number of results in a single set may be found by dividing the value of the probable error of a single result by the square root of the number of results in the set, or—

$$E_m = \pm \frac{E_1}{\sqrt{n}} \qquad \text{.....(2)}$$

or, from (1)

$$E_m = \pm\ 0{\cdot}67 \sqrt{\frac{\Sigma\ d^2}{n\ (n-1)}} \qquad \text{.....(3)}$$

Thus for the 21 results of the no-manure trials with cotton,

$$E_m = \pm \frac{1{\cdot}3{\cdot}3}{\sqrt{21}} \qquad \text{(from equation (2)).}$$

$$= \pm\ 26{\cdot}9 \text{ lb.}$$

This, expressed as a percentage of the mean (514), becomes ±5·23 per cent. The figure implies that it is even chances for or against the mean of any set of twenty-one results of no-manure trials falling inside or outside the limits 5·23 per cent of 514 on either side of the value 514, i.e. falling between (514 + 26·8) and (514 – 26·8), or 540·8 and 487·2 lb. of seed-cotton per acre.

Taking Harland's figures of ±5·3 per cent. as a more accurate value of E_1, and applying the equation, we arrive at the following value for E_m for *any set of three* plot trials in any one year of the manurial experiment :—

$$E_m = \pm \frac{E_1}{\sqrt{n}}$$

$$= \pm \frac{5{\cdot}3}{\sqrt{3}}$$

$$= \pm\ 3{\cdot}1 \text{ per cent.}$$

III. The Probable Error of a Difference. (E_d).

When we come now to examine the specific effect of different manures on the yield of, say, seed-cotton, we have to compare the results obtained in plot trials for each of the manures in turn with those obtained with no manure Consider, for example, the case of the effect of potash manuring on the yield of seed-cotton at the St. Vincent Experiment Station, as indicated by the figures obtained by Harland. The mean yield of the no-manure trials during the seven year period was 514lb. of seed-cotton per acre, and this is the mean of twenty-one results. The mean yield of the potash manure trials during the same period was 730 lb., and this figure is also the mean of twenty-one results. Expressing the first figure as 100, the second becomes 142, and the difference (which represents the percentage increase in the yield due to the effect of potash manuring) is thus 42 per cent. of the no-manure figure.

Now, had many more results been obtained by multiplication of the number of plots, the percentage difference between the mean yields of the no-manure plots and the potash plots would have been not 42 per cent., but something either greater

or less than this amount. Hence there is a probability of error attached to the figure 42 per cent. as representing the difference between two mean yields.

The probable error of a difference implies that *it is even chances for or against that difference falling inside or outside the limits of the probable error.*

The mathemetical expression which has been deduced for evaluating the probable error of a difference is –

$$E_d = \pm E_m \sqrt{2} \quad \text{.....(4)*}$$

where E_m = the probable error of the mean of either result.

Combining equations (2) and (4) we get

$$E_1 = \pm \frac{E_1 \sqrt{2}}{\sqrt{n}} \quad \text{.....(5)}$$

We may use this equation to obtain a value for the probable error of the difference between the yield results of any two sets of three plots each, of which one set received potash and the other set no manure. Taking Harland's value $E_1 = \pm 5{\cdot}3$, and noting that 'n' here is equal to 3, since each set of results includes the yield figures for three plots, we obtain the result—

$$E_d = \pm \frac{5{\cdot}3 \times 1{\cdot}41}{\sqrt{3}}$$

$$= \pm \frac{7{\cdot}47}{1{\cdot}73}$$

$$= \pm 4{\cdot}3 \text{ per cent.}$$

This figure implies that if we compare the mean yield results of any two sets of three plots, one set having been manured with potash and the other having received no manure, the chances are even that the difference between them will fall inside or outside the limits 4·3 per cent on either side of 42 per cent., i.e. will fall between 42 + 4·3 and 42 – 4·3 or 46·3 per cent, and 37·7 per cent. of the no-manure mean result.

IV. The Significance of Any Result.

We have seen that the mean yield of the potash plots may be represented by the figure 142, when that of the no-manure plots is 100. Each of these mean results is affected by the same probable error (E_m), which we found by calculation to be ±3·1 per cent. In comparing the results, we therefore multiplied the probable error of each by $\sqrt{2}$ to get the probable error of the difference This works out at ± (3·1 × 1·41) = 4·3 per cent., as has already been demonstrated. Now the difference between

*It is to be noticed that the formula $E_d = \pm E_m \sqrt{2}$ may only be used when the fluctuations in the two variables that are being compared are independent of one another. It frequently happens instatistical examinations of results of agricultural and other investigations that interelated factors are under consideration. In these cases the formula quoted cannot be used, since it does not hold for dependent variables.

the mean yield results is (142 – 100) or 42 per cent., and this is $\frac{42}{4{\cdot}3}$ or 9·7 times the probable error of the difference.

Tables have been constructed from which the odds for or against any difference obtained in comparative experiments (such as the one under consideration) being due to accidental error, can be found by inspection. Two tables of this kind are reproduced as an appendix to this article. They have been copied from Tables IV and V of Professor Wood's paper (2, ii). 'The interpretation of experimental results' (Supplement to *Journal of the Board of Agriculture*, 1911, pp. 25 and 26). The first table refers to differences which are in either direction, and the second, to differences which are in one direction only; (for example, a definite gain or loss due to the effect of any factor which we are investigating).

In measuring the effect of potash manure on the yield of seed-cotton, we are definitely measuring an increase, and hence the second table is used. By reference to it (column 1) we see that a difference of 9·7 times the probable error indicates odds of many thousands to one, for the highest difference given in the table is five times the probable error, and for this, odds of 2,700 to 1 are indicated

The difference, 42 per cent., between the yields of potash plots and no-manure plots is obviously a very significant figure, and points definitely to the difference as being directly due to the effect of potash manuring. The *degree of significance* of a resut is usually measured by *the number of times the difference between the result and a standard is greater than the probable error.*

In our example, the significance of the result 140 as representing the yield of cotton on plots manured with potash is measured

$$\text{by } \frac{140 - 100}{4{\cdot}3} = \frac{40}{4{\cdot}3} = 9{\cdot}7$$

It has been agreed to accept odds of nothing less than 30 to 1 in agricultural experiments in which comparative trials are being made. Reference to the second table above mentioned, shown that such odds necessitate a difference of 2·7 times the probable error of the difference. In our example, the probable error of the difference is ± 4·3 per cent., and 2·7 times this is ±11·6 per cent Hence if the yield of plots receiving potash manure exceeds that of plots receiving no manure by anything greater than 11·6 per cent., that excess may be considered as being directly and certainly due to the effect of potash manuring. The minimum excess found in our case is 37 7 per cent., which exceeds 11·6 per cent. by 26·1 per cent., and this latter figure may be taken as representing the increased yield due to the effect of potash manuring.

V. The Number of Plots Needed to Attain any Desired Degree of Precision in Agricultural Experiments.

In calculating the number of plots needed to give a difference which we are prepared to accept as indicative of the direct effect of some factor that we are investigating, the procedure given below is usually followed,

1. Assume that odds of 30 to 1 are indicative of certainty that the difference in the mean yields of plot trials in two series of trials to be compared is due to the direct effect of the factor we are studying.

2. Assume that this difference may be in *either* direction, that is, that the second mean value may be either greater or less than the first.

3. Use the first table * given in the appendix. Look along the line containing the 30 to 1 odds and note that the difference between the two mean results *in terms of the probable error of each mean result* is 4·51 (column II).

4. Divide the value of the difference we are prepared to accept, say, 10 per cent., by 4·51, and hence get the *probable error of the mean*, e.g. $\frac{10}{4{\cdot}51} = 2{\cdot}21$ per cent., $= E_m$.

5. To find how many plots are needed in order to reduce the probable error of the mean result to this figure (2·21 per cent.), apply the formula :—

$$E_m = \frac{E_1}{\sqrt{n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{or } n = \frac{E_1^{\,2}}{E_m^{\,2}}$$

where E_1 = the probable error of *a single result.*
E_m = the probable error of *the mean result* of either series.
n = the number of plots in the experiment.

In applying this formula, the value of E_1 must be known. This can be taken as 5 per cent. for manurial experiments with cereals and roots in England; 8 per cent. for manurial experiments with sugar-cane in the Leeward Islands, or 5·3 per cent. for manurial experiments with cotton in St. Vincent (see p. 210).

(a) Taking E_1 as 5 per cent. (English result),

$$n = \frac{5^2}{2{\cdot}21^2}$$

$$= \frac{25{\cdot}5}{5}$$

$$= 5 \text{ plots needed.}$$

---

* If the difference is expected to be in *one* direction only, the second table should be used instead of the first.

(b) Taking E_1 as 8 per cent. (Leeward Islands result)

$$n = \frac{8^2}{2{\cdot}21^2}$$

$$= \frac{64}{5}$$

$$= 13 \text{ plots needed.}$$

Finally, taking E_1 as 5·3 per cent. (Harland's result for manurial experiments with cotton in St. Vincent),

$$n = \frac{5{\cdot}3^2}{2{\cdot}21^2}$$

$$= \frac{28{\cdot}5}{5}$$

$$= 6 \text{ plots needed.}$$

VI. Determination of the Odds that One Result of an Agricultural Experiment is Better than Another.

Suppose we wish to decide what are the odds in favour of a certain result of an agricultural experiment being better than another, (for example, one manure being more effective in increasing the yield of a certain crop than another, or the cropping power of one botanical variety of a plant being higher than that of another, etc.). The method of procedure depends on the conclusions which have been obtained in the foregoing considerations, and is briefly as follows. Here again, an actual example taken from Harland's results in manurial experiments with cotton in St. Vincent will be worked out in order to demonstrate the method.

1. First determine the percentage probable error of a singl result (E_1) in experiments such as the one that is being perform ed, or assume a value for E_1 in the light of former research. F o example, we might accept E_1 as 5 per cent in a manurial experir ment on cereals or roots in England ; 8 per cent. in a manuria- experiment on sugar-cane in the Leeward Islands or 5·3 per cent in a manurial experiment on cotton in St. Vincent (see p. 210).

Suppose we choose for illustration, the determination of the odds that the increased yield of seed cotton on plots manured with phosphate over that on plots receiving no manure in the St. Vincent experiments is directly due to the effects of the phosphate manuring. In this case we n ay take Harland s estimation of the magnitude of the probable error of a sin gle result, which is ± 5·3 per cent.

2. We next apply the formula $E_m = \frac{E_1}{\sqrt{n}}$ in order to find E_m, the probable error of the mean of either series of no-manure trials or of phosphate-manure trials. In our example, $E_1 = \pm 5{\cdot}3$ and n = the number of trials, or 3 so that—

$$E_m = \pm \frac{5{\cdot}3}{\sqrt{3}} = \pm 3{\cdot}1 \text{ per cent.}$$

3. Since we are comparing two mean results, each of which is affected by this probable error of ± 3·1 per cent., we now calculate the probable error of the difference from the formula $E_d = E_m \sqrt{2}$. We thus find that $E_d = \pm (3{\cdot}1 \times 1{\cdot}41) = \pm 4{\cdot}3$ per cent. Comparing the effect of manuring cotton with phosphate with that of applying no manure, we find, therefore, as the result of three plot trials, that there is a difference of 18 per cent. (see Table I of Harland's paper, p. 31) in favour of phosphate manuring, with a probable error in the difference of ± 4·3 per cent.

4. We note that the difference (18 per cent.) is about four times the probable error of the difference $\left(\frac{18}{4{\cdot}3} = 4{\cdot}2\right)$ and that it is always in the same direction.

5. From the second table (see Appendix) we find that the chances that phosphate manure really does produce an increased yield of seed-cotton are about 290 to 1, and we conclude, therefore, that a direct benefit does follow from manuring cotton with phosphate, under the conditions that obtain at the St. Vincent Experiment Station.

(It may be noted that the method of procedure in finding the odds in favour of one mean result being better than another is the exact converse of that used in finding how many plot trials are necessary to attain any desired degree of precision in an agricultural experiment.)

Summary of Results.

A. *Meaning of symbols used.*

E_1 = The probable error of a single result.

E_m = The probable error of the mean of a number of results.

E_d = The probable error of the difference between two results.

B. *Formulae employed in calculating the above probable errors.*

(1) $E_1 = \pm 0{\cdot}67 \sqrt{\frac{\Sigma d^2}{(n-1)}}$

where Σd^2 = the sum of the squares of the differences between each result and the mean

n = the number of results in the trial.

(2) $E_m = \pm \frac{E_1}{\sqrt{n}}$

where n = the number of results in the trial.

(3). $E_m = \pm 0{\cdot}67 \sqrt{\frac{\Sigma_d^2}{n(n-1)}}$ (from 2).

(4). $E_d = \pm E_m \sqrt{2}$

(5). $E_d = \pm \frac{E_1 \sqrt{2}}{\sqrt{n}}$ (from (2) and (4).

C. *Certain facts to be remembered in applying the formulae in attempts to interpret the results of agricultural experiments.*

(i) In comparing the results of two series of trials it is customary to accept odds of 30 to 1 in favour of the difference being significant.

(ii) By the use of tables (such as those reproduced as an appendix to this article) odds in favour of a difference being significant may be translated into terms of the probable error, (E_d or E_m).

(iii) Pending the accumulation of further information, the following figures may be accepted as being the probable errors of a single result in certain agricultural experiments:–

(a) Manural experiments with cereals and roots in England, $E_1 = \pm 5$ per cent.

(b) Manural experiments with sugar-cane in the Leeward Islands, $E_1 = \pm 8$ per cent.

(c) Manural experiments with cotton at the St. Vincent Experiment Station, $E_1 = \pm 5{\cdot}3$ per cent.

APPENDIX.

FIRST TABLE OF ODDS.

(Differences measured in either direction.)

Column I. Difference from the mean in terms of the probable error of the difference.	Column II. Difference between two mean results in terms of the probable error of each mean result.	Column III. Odds against such a difference occurring under uniform conditions.
1·00	1·41	1 to 1
1·25	1·76	3 „ 2
1·44	2·03	2 „ 1
1·71	2·41	3 „ 1
1·90	2·68	4 „ 1
2·00	2·83	9 „ 2
2·05	2·87	5 „ 1
2·50	3·53	10 „ 1
2·93	4·13	20 „ 1
3·00	4·24	22 „ 1
3·20	4·51	30 „ 1
4·00	5·66	140 „ 1
4·90	6·93	1,000 „ 1
5·00	7·07	1,350 „ 1

SECOND TABLE OF ODDS.
(Differences measured in one direction only.)

Column I.	Column II.	Column III.
Difference from the mean in one direction only in terms of the probable error of the difference.	Difference between two mean results in one direction only in terms of the probable error of each mean result.	Odds against such a difference occurring under uniform conditions.
1·00	1·41	3 to 1
1·25	1·76	4 „ 1
1·44	2·03	5 „ 1
1·58	2·23	6 „ 1
1·71	2·41	7 „ 1
1·81	2·55	8 „ 1
1·90	2·68	9 „ 1
2·00	2·83	10 „ 1
2·48	3·50	20 „ 1
2·70	3·81	30 „ 1
2·89	4·07	40 „ 1
3·00	4·24	44 „ 1
3·03	4·28	50 „ 1
3·44	4·85	100 „ 1
4·00	5·66	290 „ 1
5·00	7·07	2,700 „ 1

NOTE ON DR. HARLAND'S RESULTS OBTAINED IN MANURIAL EXPERIMENTS WITH COTTON AT THE ST. VINCENT EXPERIMENT STATION.

Table I, page 31, of Dr. Harland's paper quoted in the last article (*West Indian Bulletin*, Vol. XVIII, pp. 20-33), contains the yield results obtained in the plot trials with various manures carried out in 1912 to 1918 at the St. Vincent Experiment Station The method of planning and laying out the plots is not free from objection, as may be gathered from the discussion at the commencement of the foregoing article, considered in connexion with the account given in another paper by Dr. Harland (*West Indian Bulletin*, Vol. XVI, pp. 199-202), in which the arrangement of the plots at the St. Vincent Station is described.

The whole subject of agricultural experiments is beset with difficulties, and much attention has recently been drawn to the unscientific manner in which many field trials have been conducted in the past.

In St. Vincent, as in most of the other British West Indian islands, lack of space at the experiment stations usually prohibits the carrying out of manurial trials in the approved modern manner. The proper multiplication of the plots receiving different manurial treatments is thus frequently impossible, so that the 'chess board' method[3], as successfully employed in experiments with cereals in England, cannot generally be used in the smaller West Indian islands. The relatively large size of the individual plants under investigation in the West Indies, is also an important factor in limiting the number of plots that can be laid out in an experiment station of small area. Large plants require large plots if a sufficiently great number of them are to be planted in any one plot so as to reduce errors due to individual characteristics of the plant.

Professor Ehrenburg [10] of Göttingen, has recently insisted on a previous treatment of the whole of the land to be used for manurial trials in such a way that a generally uniform and high degree of fertility is impressed on the soil before the effects of any particular manures are investigated by means of trial plots laid out on the land.

In the St. Vincent experiments, the soil at the experiment station was obviously deficient in potash at the commencement of the trials. During the course of the experiments, the no-manure plots have been exhausted of potash, whereas the plant plots have been steadily improved. This fact will cause the probable error due to plot variations to be greater than it should be, had the plots originally possessed the necessary supply of potash for the needs of the cotton plant.

In comparing the yields of plots receiving any specified manurial treatment (for example, potash manuring) with those of plots receiving no manure, a better estimate of the beneficial effects of the treatment would perhaps have been gained, by noting the differences in yield between the three pairs of most nearly adjacent plots, and thus approximately to the chess-board method of experiment.

It is possible, from Dr. Harland's results to obtain values of the probable error of a single result due to plot errors alone, and of the probable error due to the combined effect of plot errors and seasonal errors, and so to analyse the variation into that due to plot errors alone, and that due to seasonal errors alone.

At page 21, paragraph 1, of Dr Harland's paper (*loc cit*), the probable errors of a single result for each of the seven years 191 -18, are tabulated thus : –

Season.	Probable Error. per cent.
1912-13	13·7
1913-14	20·6
1914-15	6·9
1915-16	10·8
1916-17	15·2
1917-18	15·2
1918-19	10·4

These values for the probable error were obtained after eliminating the effects of the various manurial treatments, as explained in the sentence immediately following the table. The method also eliminates the effects of the seasonal variations in rainfall, etc., since the average of *each trial* of plots was taken as 100.

1. By squaring and averaging the figures in the table, and then finding the square root of the average, the value 13·87 per cent. is obtained as the probable error of a single result *due to plot errors alone.* This is the probable error which one is likely to obtain, on an average, by a single year's observations.

2 In order next to obtain a value for the probable error *due to the combined effect of both plot errors and seasonal errors,* the following calculation is made.

The absolute figures for each group of twenty-one observations on a triad of plots are first reduced to an average of 100, that is, they are calculated as percentages of the mean of the group over the seven-years' period. The deviations from the mean of 100 are written down, and the sum of the squares of these deviations then calculated. Finally, by applying the formula $E_1 = \pm 0{\cdot}67\sqrt{\frac{\Sigma d_2}{(n-1)}}$ the probable error of a single result (i.e. E_1) is determined.

We obtain the figures 21·79 per cent. by this process of calculation, as applied to Dr. Harland's yield figures.

3. To find the probable error due to seasonal errors alone, the two results obtained in the foregoing calculations are squared and subtracted. The square root of the difference is then taken

and this represents the probable error due to seasonal effects alone. Thus—

		square.
Probable error due to plot errors plus seasonal errors :—	21·79 per cent.	474·9
Probable error due to plot errors alone:—	13·87 „	192·5
	Difference :—	282·4
Square root of difference:—	16·80 per cent.	
(=Probable error due to seasonal errors alone.)		

The result is interesting, in that it indicates the relatively high value which the probable error due to seasonal climatic variations occurring in St. Vincent possesses. It also suggests that great caution should be exercised when the yield results for different seasons are being compared, a warning which is too often ignored by agricultural experimenters.

The [illegible] wishes to acknowledge his indebtedness to G. Udny Yule, Esq., M.A., Lecturer in Statistics, Cambridge University, England, for his criticism and help in the preparation of this and the foregoing article on the interpretation of results of agricultural experiments.

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